

Potentials for higher recycling of nutrients in organic wastes from farming, industry and households

THE CURRENT SITUATION AND SCENARIOS FOR FUTURE DEVELOPMENT IN DANISH NUTS2 REGIONS

November 2024

Front page photo: Example of bio-based fertilisers; dried manure pellets.

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Preface

The present report has been prepared in connection to the Baltic Interreg co-funded project, CiNURGi, Task A1.1: "Assess potential for nutrient recycling (NR) to improve national and regional nutrient balances".

The CiNURGi project aims at supporting the development towards a circular economy for nutrients in the Baltic Sea Region. The initiative focuses on upgrading current infrastructure and technology to enhance nutrient recycling from organic wastes from agricultural, municipal, and industrial sources. CiNURGi is led by RISE Research Institutes of Sweden, supported by a consortium of 24 partners and 13 associated organizations from various countries around the Baltic Sea.

The assessments of nutrient potentials and balances takes as far as possible basis in validated and official information, including statistics published by Statistics Denmark and Eurostat, supplemented with other information sources and own calculations and estimates.

The report is authored by Henning Lyngsø Foged.

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Organe Institute

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Definitions of terms used in the report

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|-------------------------|--|
| Bio-based fertilisers | Bio-based fertilisers are defined in a position paper of the European Sustainable Phosphorus Platform (ESPP), found in a final draft at https://shorturl.at/YvSNc , or any possible later updates. |
| Field effect | Field effect or N field effect relates to the share of the nitrogen in livestock manures (ex storage), that Danish crop producers according to the legislation is responsible for. The regulated field effect depends on the manure type, and is typically 75-80% (Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen, 2023a). This means, that 20-25% of the nutrients in livestock manures are not accounted for and may be lost to the environment. |
| Nutrient recycling | <p>Nutrients relates in this context to the major plant nutrients nitrogen (N) and phosphorus (P).</p> <p>Recycling means in this connection that N and/or P stems from a crop, that it at some stage has been contained within organic wastes and is returned as a crop fertiliser.</p> |
| Nutrient Use Efficiency | NUE is the percentage of N or P in any given fertiliser raw material that is taken up by a crop. For example, if an organic waste contains 100 kg N in total, and this is used for crop fertilisation with or without prior processing into bio-based fertilisers, and 87 kg N is found in the harvest of the crop that was fertilised with it, the NUE for N is 87%. |

Summary in English

Denmark needs to reduce its nitrogen fertiliser consumption with 37% before 2030 in order to live up to EU's Farm-to-Fork goal of a 20% reduction in fertiliser consumption, assuming the baseline is 2013/14. Similarly, the phosphorus fertiliser consumption shall be reduced with 6%, but given the relatively high phosphorus balance in Danish farming, it would be possible with further reductions. The current Danish Water Action Plan is in this respect aiming at a 38,400-ton nitrogen and 4-ton phosphorus reduction of losses to the aquatic environment before 2027.

A feasible way for reach of the reduction goals is to use nutrients in organic wastes from farming, households and industry better, via a higher recycling rate and by improving the Nutrient Use Efficiency. Also, the "Agreement on a green Denmark" (Regeringen, 2024) will have an impact on the fertiliser consumption, since it determines that about 15% of the agricultural area will be taken out of cultivation and not anymore fertilised, thereby substantially contributing to reach the abovementioned reduction goals.

Considering the dynamics of our society combined with the foreseen time lag from reacting on the conclusions of this reports, including time for needed policy decisions and practical implementation, the analyses in this report apply future scenario perspectives, not least made relevant in the light of the "Green agreement". The scenarios are in general applying a 10-year perspective, meaning attempting to foresee the situation by end of 2034. The "Do nothing" scenario has as the most important pre-condition assumed the "Green agreement" will be implemented, but "business as usual" with respect to the use of organic wastes for fertilisation, with or without prior processing to turn them into bio-based fertilisers and/or improving their NUE. The "Optimised" scenario builds in the "Do nothing" scenario, and assumes furthermore as the most important additional pre-condition, that losses of nutrients in farming is halved via a wider application of state-of-the-art technology for processing and handling of organic wastes with the aim to increase nutrient recycling and is in some cases also assuming future use of innovative processing technologies that are currently being developed.

The analysis of nutrient balances in Denmark and Danish NUTS2 regions shows that it would be possible already in the current situation, to reduce the import of P fertilisers with 90%, since Denmark overall only has a small P deficit compared to the demand for crop production. Overall, the self-sufficiency with N and P from recycled organic wastes is 51 and 98%, respectively.

Of 192,990 recycled tonnes N, 87% relates to livestock manures. The regulated N field effect of about 77.5% means that it is accepted that 22.5% or 48,635 tonnes N may be lost to then environment.

Overall, the analysis exposes the huge role of farming in future solutions for increased recycling and self-sufficiency with plant nutrients and, vice versa, for improving the quality of air and water. The

figures also reveal a very low recycling of nutrients from other organic waste types, especially those in our wastewaters.

The impact of an implemented "Green agreement" would be substantial for the nutrient balances and self-sufficiency. The self-sufficiency with N and P fertilisers could be raised to 55 and 109%, respectively. A further introduction of measures to halve losses of nutrients in farming via a required N field effect and an average P balance on farms of 0 kg P, as broadly assumed in the "Optimised" scenario, would give basis for self-sufficiencies of 65 and 123% with N and P fertilisers, respectively. These measures would save waters and air for emissions of about 30,000 tonnes of N and 9,000 tonnes of P, or vice-versa save farmers for buying these amounts of nutrients in inorganic fertilisers. When self-sufficiencies are above 100%, there is theoretically a possibility for export of P out of the country, or to use it in livestock feeding etc.

Nutrients in municipal and industrial wastes can play an increasing role, and the newly implemented collection of household food wastes contributes to the nutrient supply in a positive way.

The amounts of nutrients that is recycled from slaughterhouse wastes and dead animals was assessed with even very large uncertainty and relatively loose assumptions. Similarly, it was recognised, that information about nutrient turnover related with food wastes largely does not exist. It appears to be inappropriate in relation to a variety of policy goals, that companies working with nutrient rich organic wastes, either public owned companies or companies that like DAKA is given total dominance and responsibility for handling specific waste types, are not required to have nutrient accounts, set goals for their nutrient recycling and openly publish figures about their activities.

Dansk sammenfatning

Danmark skal reducere sit forbrug af kvælstofgødning med 37 % inden 2030 for at leve op til EU's Farm-to-Fork-mål om en 20 % reduktion i gødningsforbruget, forudsat at udgangspunktet er 2013/14. Tilsvarende skal forbruget af fosforgødning reduceres med 6 %, men givet den relativt høje fosforbalance i dansk landbrug vil det være muligt med yderligere reduktioner. Den nuværende danske Vandmiljøplan sigter i den forbindelse mod en reduktion af tabet til vandmiljøet med 38.400 tons kvælstof og 4 tons fosfor inden 2027.

En mulig måde at nå reduktionsmålene på er at bruge næringsstoffer i organisk affald fra landbrug, husholdninger og industri bedre via en højere recirkulering og ved at forbedre effektiviteten af næringsstofforbruget. Ligeledes vil "Aftalen om et Grønt Danmark" (Regeringen, 2024) have betydning for gødningsforbruget, da den bestemmer, at omkring 15 % af landbrugsarealet skal tages ud af dyrkning og ikke længere gødes, og derved bidrager væsentligt til nå ovennævnte reduktionsmål.

I betragtning af dynamikken i vores samfund kombineret med den forudsete tidsforsinkelse fra at reagere på konklusionerne i denne rapport, herunder tid til nødvendige politiske beslutninger og praktisk implementering, anvender analyserne i denne rapport fremtidige scenarier, ikke mindst gjort relevante i lyset af "Aftalen om et Grønt Danmark". Scenarierne anvender generelt et 10-årigt perspektiv, hvilket betyder et forsøg på at forudse situationen inden udgangen af 2034. "Gør ingenting"-scenariet har som den vigtigste forudsætning, at "Aftalen om et Grønt Danmark" vil blive implementeret, men "business as usual" med hensyn til anvendelsen af organisk affald til gødskning, med eller uden forudgående behandling for at omdanne det til biobaserede gødninger og/eller forbedre deres plantetilgængelighed. "Optimeret"-scenariet bygger på "Gør ingenting"-scenariet og forudsætter endvidere som den vigtigste yderligere forudsætning, at tabet af næringsstoffer i landbruget halveres via en bredere anvendelse af teknologi i landbruget, som øger recirkuleringen af næringsstoffer, og scenariet forudsætter i nogle tilfælde også fremtidig brug af innovative forarbejdningssteknologier, der er under udvikling.

Analysen af næringsstofbalancen i Danmark og danske regioner viser, at det allerede i den nuværende situation vil være muligt at reducere importen af P-gødning med 90 %, da Danmark samlet set kun har et lille P-underskud i forhold til behovet for gødskning. Samlet set er det i dag muligt at have en selvforsyning med N og P der er recirkuleret via organisk affald på henholdsvis 51 og 98 %.

Af ca. 192.990 tons recirkuleret N vedrører de 87 % husdyrgødning. Den lovgivne kvælstofeffekt for husdyrgødning på omkring 77,5% i gennemsnit betyder, at det er accepteret at 22.5% eller 48.635 tons N ender i naturen som situationen er nu.

Samlet set bekræfter analysen landbrugets enorme rolle i fremtidens løsninger for øget genanvendelse og selvforsyning med plantenæringsstoffer og omvendt til forbedring af luft- og vandkvaliteten. Analysen afslører også en meget lav genanvendelse af næringsstoffer fra andre organiske affaldstyper, især dem der er i vores spildevand.

Virksomheden af en implementeret "Aftalen om et Grønt Danmark" vil være væsentlig for næringsstofbalancen og selvforsyningen, der ville kunne hæves til 55 og 109 % for henholdsvis N og P gødning. Hvis der yderligere indføres foranstaltninger til at halvere tabet af næringsstoffer i landbruget via krav om en højere kvælstofeffekt og en gennemsnitlig P-balance på bedriftsniveau på 0 kg P per ha, som er blandt de væsentligste yderligere forudsætninger i det opstillede "Optimeret"-scenarie, ville selvforsyning kunne øges til 65 hhv. 123 % for N- og P-gødning. Tiltagene ville kunne spare vand og luft for emissioner på ca. 30.000 tons N og 9.000 tons P, eller omvendt spare landbruget for at købe disse mængder næringsstoffer via uorganisk gødning. Når selvforsyningen er over 100%, er der teoretisk set en mulighed for at eksportere P ud af landet, eller at oparbejde det til brug i husdyrfoder mv.

Næringsstoffer i kommunalt og industrielt affald kan spille en stigende rolle, og den nyligt implementerede indsamling af madaffald fra husholdningerne bidrager positivt til næringsstofforsyningen.

Mængden af næringsstoffer, der genanvendes fra slagteriaffald og døde dyr, blev vurderet med endog meget stor usikkerhed. Tilsvarende blev det erkendt, at information om næringsstofomsætning relateret til madaffald stort set ikke eksisterer. Det forekommer at være uhensigtsmæssigt i forhold til en række politiske mål, at virksomheder, der arbejder med næringsholdigt organisk affald, hvad enten det er offentligt ejede virksomheder eller virksomheder, der ligesom DAKA har total dominans og ansvar for håndtering af specifikke affaldstyper, ikke har krav om næringsstofregnskaber, mål for deres recirkulering af næringsstoffer eller pligt til at offentliggøre tal om deres aktiviteter.

1: Introduction and background

The Interreg Baltic co-financed CiNURGi project works for improving recycling of nutrients in organic wastes from farming, households, and industries. The project envisions a higher nutrient recycling and foresees that the unlocking of that potential would be facilitated by improved possibilities for processing organic wastes into bio-based fertilisers in NUTS2 regions with excess of plant nutrients for the purpose of transporting these to NUTS2 regions that are in deficit of plant nutrients, hence avoiding emissions of nitrogen (N), phosphorus (P) and greenhouse gases (GHG) in the NUTS2 regions in excess, and reducing the consumption of inorganic fertilisers in the NUTS2 regions in deficit.

1.1: NUTS2 regions

NUTS2 regions are statistical regions as defined by EU's statistical service, Eurostat. Figure 1 shows a map of Danish NUTS2 regions. A typical size of a NUTS2 region makes it economically feasible to distribute nutrient-containing biomass within NUTS2 regions with a minimum or without prior processing, for instance as wet biomass, to farms where the wet biomass is used for crop fertilisation. Transporting nutrients out of a NUTS2 region would in many cases entail a transport of more than 100 km, wherefore processing into more nutrient concentrated bio-based fertilisers in such cases becomes cost-efficient.

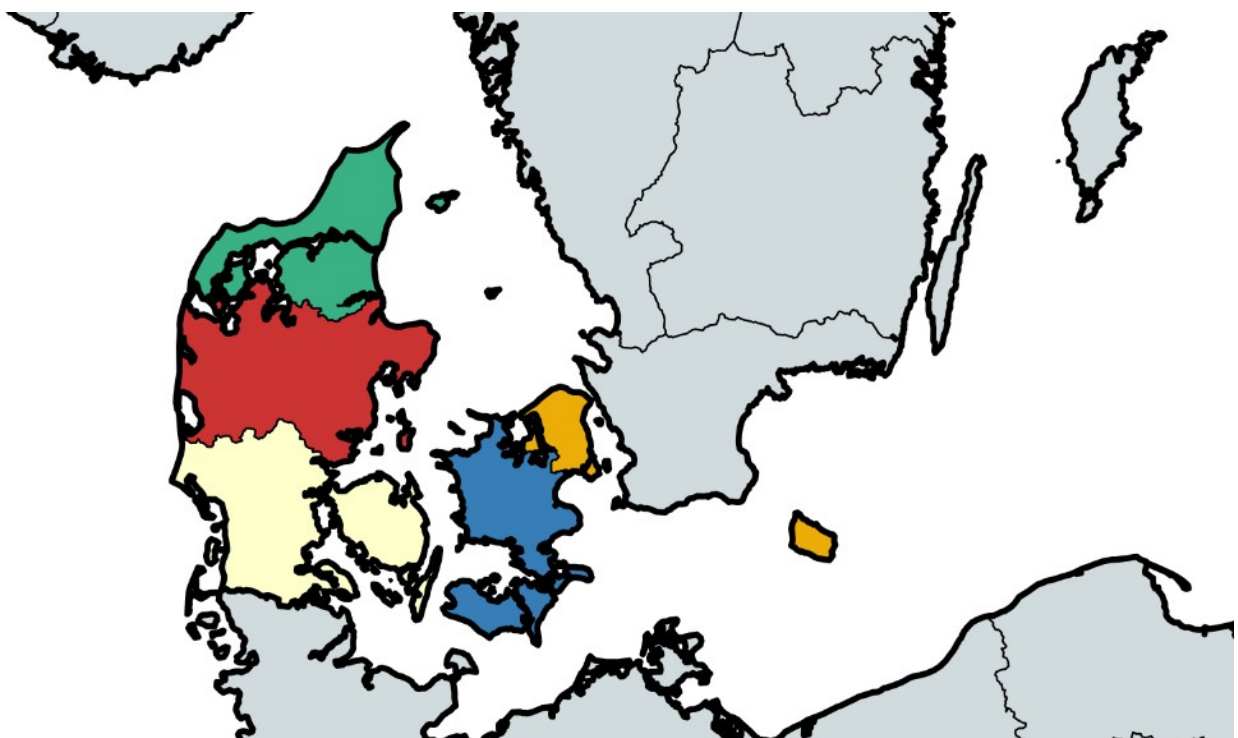


Figure 1: Danish NUTS2 regions (prepared with <https://www.mapchart.net/europe-nuts2.html>): DK01 - Region Hovedstaden – orange, DK02 - Region Sjælland – blue, DK03 - Region Syddanmark – yellow, DK04 - Region Midtjylland – red, and DK05 - Region Nordjylland – green.

1.2: CiNURGi policy areas

CiNURGi is positioned in a crossroad of several policy areas, whereof some important are waste handling, environmental protection, critical materials, soils and climate change. In an EU Strategy for the Baltic Sea Region (EUSBSR) (European Commission, 2012) context, the project is mainly associated with the policy areas PA Nutri, PA Bioeconomy and PA Hazards.

In the case of Denmark, CiNURGi would potentially provide solutions that would contribute to the reach of current policy goals:

- The Danish Government has with the current water action plan, Water Action Plan 3 (2021-2027), according to the Danish Environmental Protection Agency¹ determined a goal to reduce losses of N to the aquatic environment, including the Baltic Sea, to 38,400 ton of nitrogen to reach a desired ecological status. The plan includes measures for a reduction of 13,100 ton of nitrogen in total, including 6,500 ton of nitrogen through targeted regulation, and 3,900 ton to be achieved through an agricultural reform and voluntary collective efforts. With an agricultural area in Denmark in 2023 of 2,625,537 ha according to Statistics Denmark², the goal for reduction of N emissions to the aquatic environment equals app. 5 kg N per ha, or 25% of the emissions of 19.6 kg N per ha in 2021.

The mentioned goals are alone related to N losses to the aquatic environment, in Danish policy context related to measures for mitigating leaching and runoff. In reality, measures to reduce N losses to the air via ammonia volatilisation also contribute to the general increase of the recycling of nutrients in organic wastes, since lowered air emissions largely means that measures are taken to conserve the N content of organic wastes that as a consequence will have higher fertilisation effect.

- The focus on P emissions has in Denmark a lower priority. The mentioned Water Action Plan 3 has set a goal to reduce losses of P to lakes with 4 ton, at least. The goal appears to be negligible, considering that Denmark according to the latest available statistics³ has a balance of 7 kg P per ha, which theoretically should be 0, and for EU as a whole is an average of 1.2 kg/ha. The Danish Government has introduced limits on phosphorus fertilization, in specific flat rates of 30-35 kg P per ha, depending on the fertiliser type (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2022.). Denmark has with this omitted to implement HELCOM Recommendation 28E/4 (2007) that prescribes a max of 25 kg P to be fertilized per ha.

¹<https://mst.dk/erhverv/rent-miljoe-og-sikker-forsyning/vandmiljoe/vandomraadeplaner/overblik-vandomraadeplanerne-2021-2027/vandomraadeplanerne-2021-2027>

²<https://www.statistikbanken.dk/statbank5a/selectvarval/define.asp?PLanguage=0&subword=tabel&MainTable=AFG5&PXSIId=235610&tablestyle=&ST=SD&buttons=0>

³ https://ec.europa.eu/eurostat/databrowser/view/aei_pr_gnb/default/table?lang=en

- Regarding goals for greenhouse gas emissions, the Danish Government has with the Climate Law set a goal for a 70% reduction in 2030, compared to the 1990-baseline (Klima-, Energi- og Forsyningsministeriet, 2020). The Danish Government closed in June 2024 an agreement with the major NGO's representing farming and nature conservation about the frames for contributions from the farming sector to reduce GHG emissions. The "Agreement on a green Denmark" (Regeringen, 2024), in the further called "Green agreement", between the Danish Government, The Danish Agriculture & Food Council and The Danish Society for Nature Conservation outlines important aspects of the way Danish farming will develop over the coming years. While details about the implementation are currently being negotiated, a new Minister has been appointed by end of August 2024 with the specific resort area of implementing the "Green agreement", which emphasizes the scope and importance of it, and implies the substantial impacts it is expected to have on future farming in Denmark.

With EU's Farm-to-Fork strategy – one of the central pillars of the European Green Deal – the European Commission aims to see a reduction in nutrient losses of at least 50% by 2030, while ensuring no deterioration in soil fertility. This is expected to lead to a reduction in fertiliser use of at least 20%⁴. It is a common perception (De Jaegher, 2022), that the reduction target is set with 2013/14 as a baseline, and that the reduction in fertiliser use must deal with inorganic fertilisers since fertilisers based on processing of organic wastes logically will not be reduced in quantity. It is rather to be understood that the compensation for less plant nutrients via inorganic fertilisers shall come from a higher recycling of nutrients in organic wastes. The EU goal is thus going in the same direction as the Danish goal for reduction of nutrient losses.

1.3: Farm-to-Fork policy goals in relation to the consumption of fertilisers in Denmark

Table 1 shows the sale of plant nutrients in fertilisers in Denmark. The sale equal 91 kg N, 5 kg P and 17 kg K per ha cultivated area in Denmark, whereas the figures probably would be lower if they were adjusted for non-commercial use etc. Table 1 also show, what the mentioned Farm-to-Fork target means in the Danish case, as well as the needed reductions to comply with that target, assuming the consumption equal sales and that annual stock changes are insignificant. It is seen that there is a need to reduce the consumption of N-fertilisers with 37%, while reductions needed for P and K are much smaller, 6 and 3% respectively, since the consumption of these fertiliser types already were reduced after 2013/14.

EU's current common agricultural policy (CAP), running from 2021 to 2027, includes measures to support the reach of the Farm-to-Fork goals. It is expected that the CAP-policy for the next period

⁴ https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

after 2027 will be based on an evaluation of the reached status by then and comprise more concrete measures to reach the goals.

Table 1: Total sale of the main plant nutrients in fertilisers in Denmark, for 2013/14 and 2021/22 (Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen, 2015 and 2023), as well as Farm-to-Fork targets and needed reductions. The figures are given in ton, and covers the harvest years, starting 1 August.

| | 2013/2014 | 2021/2022 | Farm-to-Fork target (20% under 2013/14) | Needed reduction from 2021/22 to 2030 | |
|----------------|-----------|-----------|--|--|----|
| | | | 2030 | Ton | % |
| Nitrogen (N) | 186,820 | 238,846 | 149,456 | 89,390 | 37 |
| Phosphorus (P) | 14,046 | 11,897 | 11,237 | 660 | 6 |
| Potassium (K) | 53,384 | 44,047 | 42,707 | 1,340 | 3 |

1.4: Aim of this report

The aim of this report is on this background to analyse the balance at NUTS2 level between nutrient demand for crop production against the potential for recycling of nutrients in organic wastes from industry, farming and households.

2: Methodology

Considering the dynamics of our society combined with the foreseen time lag from reacting on the conclusions of this reports, including time for needed policy decisions and practical implementation, the report applies future scenario perspectives. The applied future perspectives are not least made necessary due to the "Green agreement", that will change the cultivated area and cropping pattern in Denmark in the coming years.

Some main methodological principles for these future scenarios are outline in the following, whereas further details are given in section 3.

2.1: Scenario definitions

The scenarios are in general applying a 10-year perspective, meaning attempting to foresee the situation by end of 2034.

In addition, the report will specifically analyse a "Do nothing" scenario and compare this with a "Optimised" nutrient recycling scenario:

- The "**Do nothing**" scenario assumes business as usual with respect to the use of organic wastes for fertilisation, with or without prior processing to turn them into bio-based fertilisers and/or improve their NUE. The scenario takes into account the consequences of the "Green agreement" and forecasts for developments in the population, and also an expected development in livestock number.
- The "**Optimised**" scenario takes basis in the "Do nothing" scenario but assumes furthermore a wide application of state-of-the-art technology for processing and handling of organic wastes with the aim to increase nutrient recycling and is in some cases also assuming future use of innovative processing technologies that are currently being developed.

Both scenarios consider forecasted, continued or assumed development in 1) resource efficiency and productivity in crop and livestock farming and the cultivated area as concerns the agricultural sector, 2) the development in number of citizens concerning organic wastes from households, and 3) an assumed development in livestock farming, since organic industrial wastes in the Danish case especially is produced by the animal food processing industry.

2.2: Farming

With farming is understood the primary agricultural sector, including crop production and livestock production at farms, horticultural holdings and greenhouses.

2.2.1: Demand for nutrients in fertilisers

- Crop production is considered with respect to its demand for input of plant nutrients via fertilisers. It includes plant production with the purpose of food and feed production in agriculture, horticulture (plantations, orchards) and greenhouse production.

The estimated demand for nutrients is for agriculture and horticulture assessed with consideration to current statistics for cropping patterns and current regulated legal maximal fertilisation (Ministeriet for Landbrug, Fødevarer og Fiskeri, 2023a) – see details in Annex 1:

- The estimated agricultural land area and cropping pattern in 2034 is based on the following considerations:
 - The “Green agreement” determines that 140,000 hectares of carbon-rich lowland soils (humus soils) incl. peripheral areas will be converted from agricultural land to nature.
 - Similarly, the “Green agreement” determines that 250,000 ha must be planted with forest, notably without any use of fertilisers or pesticides. We assume that forests will be planted at the most cost-ineffective lands, such as areas with sandy soils that gives lower productivity but has higher nutrient demands and higher nutrient losses, and lands that are more costly and difficult to cultivate, such as areas requiring irrigation, areas that are often flooded, hilly areas, and small parcels.
 - The “Green agreement” also foresees that land that is situated below sea level and currently being artificially drained shall return to sea, fjords and lakes for the sake of the environment and nature. The “Green agreement” is not specific about the exact area, but it will probably be part of the abovementioned areas that will be converted to nature or planted with forests, comprising to about 15% of the cultivated agricultural area in 2023.
 - The distribution of specific crops varies from year to year due to market conditions and regulations. The estimated cropping pattern is therefore based on assumptions for the area that will be cultivated with different crop type groups in 2034, since cropping patterns varies less within crop type groups than between crop type groups.
 - Alike the development over the past 10 years, the next 10 years are not expected to result in significant agricultural land areas shifting status to cities and roads etc.
- For the estimated nutrient demand, the following considerations are done:
 - The Danish regulations about maximally allowed fertilisation with N and P is related to six different soil texture classes (coarse sand, fine sand, irrigated sand, sandy clay, clay and humus). We have roughly assumed the future nutrient demand for various crop type groups on basis of an assumption that cultivation of humus soils has ceases in

2034 due to the "Green agreement", and given most weight to the nutrient demands for the dominant crops in each crop type group, for instance to winter wheat in the case of winter cereals, since winter wheat makes up about 80% of the area with winter cereals in Denmark.

- Historically, crop productivity has overall shown an increase of up to 1% per year, for instance due to improvements in tillage and crop management. The increase in crop productivity has happened with only minor changes in fertilisation. Tabel 2 shows the maximal allowed fertilisation per ha winter wheat at sandy clay soils in 2016 and 2023. Winter wheat is the most dominant crop in Denmark, covering about 20% of the cultivated agricultural area.

Table 2: Standard yield and maximally allowed nitrogen fertilisation for winter wheat grown at sandy clay soils (Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugstyrelsen, 2016 and 2023a)

| | Standard yield, ton/ha | | Maximal nitrogen fertilisation | |
|--|------------------------|---------|--------------------------------|---------|
| | 2016/17 | 2023/24 | 2016/17 | 2023/24 |
| Winter wheat grown at sandy clay soils | 8.1 | 9.0 | 200 | 206 |

Table 2 shows that the standard yield has increased 0.9 ton/ha over the 7-year period, equal to approximately 1.6% per year, whereas the nitrogen demand only increased with 6 kg N/ha, equal to about 0.4% per year. The standard yields and maximally allowed nitrogen fertilisation is in Denmark expressing the economically optimal nitrogen fertilisation. It is adjusted every year on basis of the newest fertiliser trials.

It should in connection to the abovementioned be kept in mind that the large increase in use of nitrogen fertiliser that appears from Table 1 covers, that the maximally allowed nitrogen fertilisation rate for crops was politically reduced in the years from 1999 to 2015, typically with about 10%, compared to the economically optimal fertilisation rate.

- The nutrient demand for greenhouse production is assessed separately on basis of statistics for the regional distribution of greenhouses and the nutrient demand for crops grown in closed and controlled greenhouse systems.
- Also, a separate assessment of the demand for nutrients in fertilisers used in private gardens is performed. There are almost 1.2 million single family houses and farmhouses in Denmark, out of 2.8 million homes in total, which typically have an ornamental garden and, in most cases, a smaller or larger self-production of spices, flowers, berry bushes, fruit trees, and in some cases also vegetables like tomato, cucumber, potatoes, leek, etc. Typically, families with single family houses and farmhouses buys fertilisers in a building supply warehouse, and considering the large number of them, it is found relevant to consider their use of fertilisers in

order to understand the total demand for nutrients. For fertiliser consumption / demand for private gardens, no statistics exists. Companies that market fertilisers must report their sales, but registrations do not comprise the type of customers. The nutrient demand in Annex 3 and Table 3 is assessed on basis of the assumption that a single-family house or farmhouse averagely uses 20 kg of a 7-1-5 all-round fertiliser annually, given the number of single-family houses and farmhouses in Annex 3.

2.2.2: Supply of nutrients from livestock manures

- Nutrients in organic wastes from farming is considered with respect to the production of livestock manures, including the part that is available for fertilisation and/or potentially could be further processed into bio-based fertilisers. Danish farming does not produce other types of nutrient-containing organic wastes that with respect to available amounts are feasible for a stable supply for direct use for fertilisation or for production of bio-based fertilisers.
- The estimation of livestock manure nutrients is based on a methodology described by Foged et al. (2011). This methodology is relevant for cases where an assessment is envisaged, but detailed pre-conditions not available. This is indeed the case for the “Do nothing” and “Optimised” 2034-scenarios that this report deals with, since the number of livestock and their productivity in 2034 would have to be assessed on basis of estimated forecasts. For the present purpose, the methodology is adjusted to include sheep and horses, and the used values for manure production per animal type is updated and aligned with the current livestock productivity in Denmark (Børsting and Hellwing, 2023), rather than being based on assessed EU averages.
- The estimation considers the abovementioned “Green agreement” along with the development in recent year, namely a decline in the number of cattle and pigs with app. 1% per year, or 11% in total compared to statistics for 2023, whereas the number of chickens, sheep and horses are expected to remain unchanged.
- Currently, Denmark has experienced a development towards a higher and higher export of piglets to mainly Germany for feeding and/or slaughtering. Thus, it is expected on basis of information from Danske Svineproducenter⁵, that 16 million piglets will be exported in 2024, while alone 14 million will be fed and slaughtered in Denmark. This mean that the manure production from fatteners is considerably lower than earlier. The development is caused by a loss of competitiveness of Danish pig production and slaughtering. Since there is nothing that gives reason to believe the situation will change back and piglets again be fattened and slaughtered in Denmark, the estimated manure production from fatteners in 2034 assumes that the current export of 45% of the piglets continue.

⁵ <https://danskevineproducenter.dk/>

- The manure production per animal, including amounts and content of N and P is based on Børsting and Hellwing (2023). A continued increase in productivity is expected for cattle, pigs and chickens, but also an increase of the feed efficiency that determines the amount of nutrients in the produced manure, and it is assumed that these two factors are likely to outweigh each other.

2.2.3: Considerations concerning the “Do nothing” and “Optimised” scenarios

The “Do nothing” scenario assumes business as usual, whereof some main characteristics comprise:

- The current regulated nitrogen field effect remains, meaning that professional crop producers are accountable for 75 and 80% of the N in the main livestock manure types, namely pig and cattle slurry respectively, whereas the demanded nitrogen effect alone is 50% for deep litter (Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen, 2023a). It is assumed that professional crop producers also in 2034 are allowed to assume that averagely around 22.5% of N in livestock manures ends in the environment, corresponding to more than 50,000 tonnes N per year. No new measures that will reduce N volatilisation and emissions from field spreading are implemented.
- No new measures are taken to reduce N volatilisation in the form of ammonia volatilisation from livestock housing and manure storages, which currently amounts to typically about 10% of the N excreted by the animals, with variations due to housing system, animal type and whether manure stores are with solid or tight cover.
- The current regulation of P fertilisation is expected to continue, meaning a flat P fertilisation limit as described above, which for a limited share of livestock farms gives incentives to export surplus P out of the farm, for instance via the use of slurry separation followed by export of the separation solids. Overdosing with P at some livestock farms can continue, and it is seldom that manure P is moved to another NUTS2 region.
- Overall, the imprecise nutrient regulation on farms in the current way, attempting to manage nutrient losses/outputs by regulating inputs of nutrients via fertiliser planning, and by taking basis in livestock manure nutrients ex storage, is continued.

It is the assessment, that in the “Do nothing” scenario, 22.5% / 15% of N and P respectively is lost after storage. With other words, the NUE for N is assumed to be 77.5% for N and 85% for P, and the manure production based on Danish standard values for manure (Børsting and Hellwing, 2023), using ex storage values.

The “Optimised” scenario assumes the following:

- Regulation of fertilisation has switched to a balance principle, where nutrients entering the farm is balanced against nutrients leaving the farm. Farms are required to comply with a certain N balance, dependent on production type, and a P balance of 0. This would give higher

incentives to use technologies to reduce ammonia volatilisation from housing, storing and field spreading, such as quick removal of manure from housing, slurry cooling, solid cover on manure storages, use of sulfuric acid or other additives to avoid N volatilisation, use of feed additives to improve nitrogen metabolism, etc. It would give higher incentives to use slurry separation to avoid over-fertilisation with P, and in the same time achieve higher bio-availability of the N part of the slurry if the crop is alone fertilised with the separation liquids.

- It is the assessment, that in the "Optimised" scenario, 5% / 0% of N and P respectively is lost during housing and storage, and a further 11.25% / 0% of N and P respectively is lost after storage. With other words, the NUE for N is assumed to be 88.75% for N and 100% for P, and the manure production calculated on basis of Danish standard values for manure (Børsting and Hellwing, 2023), using ex storage values, but increased 5% for the N values, since a smaller N volatilisation from livestock housing and manure storage is expected.

2.3: Urban wastewater

Urban wastewater is liquids that is processed at wastewater treatment plants (WWTP's), primarily based on activities such as restroom usage, bathing, food preparation and laundry. Wastewater received at WWTP's can also stem from industrial or commercial manufacturing processes. Wastewater would typically arrive at WWTP's via the sewer system, but in some cases also via bowsers in cases where it could not be channelled via the sewer system.

The quantity of nutrients in wastewaters are estimated on basis of person equivalents (pe). For Denmark, the wastewater executive order (Miljø- og Ligestillingsministeriet, 2021) determines in Article 4.5 that 1 pe is equal to 4.4 kg N and 1 kg p.

With respect to the current recycling of nutrients, The Danish Environmental Protection Agency informs in their annual waste statistics (Miljøstyrelsen, 2024) that 87,000 tonnes of sludge from WWTP's was generated in 2022, and that 74,000 tonnes, or 93% was reused on agricultural soils, presumably for crop fertilisation. However, the mentioned figures do not match. Since we from the raw waste data provided by The Danish Environmental Protection Agency alone can find information about 80,017 tonnes of sludge from WWTP's, we anticipate there is a mistake in the Waste statistics, and that 80,017 tonnes of sludge is generated at WWTPs, whereof 93% or 74,000 tonne is reused at farms.

We have studied ReWater, a WWTP under planning in Aarhus Municipality. ReWater is interesting in this connection because it will become a large WWTP in the second largest municipality of Denmark, and because ReWater is assumed to represent a WWTP of the future. Development of the coming WWTP started already in 2016 and huge efforts are given to design the plant to meet all policy aspects while it is also being built for rationalisation purposes. The case is presented below.

Our study of ReWater does not give basis for assuming any change in overall recycling of nutrients from wastewaters until 2034. The objectives of ReWater include higher nutrient recycling according to the way the project presents itself, but the ways it shall be done are not identified, and we do via contact with the project get the impression that nutrient recycling is not given much attention.

Sludge amounts for 2034 are forecasted using forecasts for number of citizens in Denmark, published by Statistics Denmark⁶ - see Annex 6.

The LEX4BIO project provides at <https://px.luke.fi/PxWeb/pxweb/en/maatalous/> some other information about sludge. We have assumed that the information in the Danish waste statistics (Miljøstyrelsen, 2024) about amounts of wastewater sludge and the share of it that is returned to farming is the most trustworthy and updated, whereas we use LEX4BIO's information about the nutrient content in WW sludge.

For sludge from WWTPs, the main focus is on its content of unwanted substances, such as medicine residues and heavy metals, whereas it is difficult to find solid information about its content of N and P, probably due to high variation and differences in technological processes and quality of the wastewater. We have assumed that N_{total} average 3.85% and P 2.6% of Dry Matter as recommended by LEX4BIO, and if the sludge has a dry matter content of averagely 20%, this equals 7.7 kg N and 5.2 kg P per tonnes wet sludge.

⁶ <https://www.statistikbanken.dk/20021>

Case: Aarhus ReWater – the treatment plant of the future

Aarhus Vand (In English: Aarhus Water) is the water treatment company of Aarhus Municipality, the second in Denmark after the number of inhabitants, 361,544 in 2023. Aarhus Vand has initiated a project for the future handling of municipal wastewater that considering the population of the municipality is expected to reach almost 600,000 inhabitants by year 2060, and in line with current policies rather will focus on utilisation of the resources in wastewater than merely being a station for final disposal of it, as signalled by the ReWater name.

Although the final decision about the exact location is yet to be taken, the plant will be situated in the Marselisborg harbour area of Aarhus, expanding a current site and simultaneously closing two other, minor wastewater treatment plants in Aarhus, and treat all wastewaters at alone two central sites in the future, besides Marselisborg, also Egå. The decision was taken by Aarhus City Council 10 years ago, where there were 17 wastewater treatment plants in the municipality, justified by a possibility to reduce costs for municipal wastewater treatment with 40% and at the same time increase the efficiency and reduce nitrogen emissions by up to 25 percent and phosphorus emissions by up to 40 percent in 2032, when the plant is expected to be in operation.

Establishing the ReWater facility is the final step of the political decision to rationalise wastewater treatment in the municipality.



"As the world's most resource-efficient treatment plant, Aarhus ReWater will contribute to a cleaner and more attractive Aarhus. A landmark for everything we can do in the city, and which we proudly want to pass on to future generations."

- Inge Halkjær Jensen, project manager for Aarhus ReWater

Aarhus ReWater will comprise i) treatment and resource utilisation, ii) removal of chemical residues and heavy metals, and iii) innovation and knowledge generation – see the visualisation above. A remarkable feature of the ReWater nitrification-denitrification basins are that they will be partially covered for the purpose of reducing odour nuisance to an absolute minimum, and as well avoid laughing gas emissions.

Inge Halkjær Jensen, project manager for Aarhus ReWater says: *"Aarhus ReWater would like to increase the recirculation of N and P nutrients to the food chain, but it must be in a more intelligent way than today, where you can end up getting chemicals and heavy metals back into the food chain. Therefore, returning sludge to agriculture is not part of the future solution in ReWater. Struvite production, which was already tested, could be one of future solutions if challenges with market competitiveness and product uniformity can be resolved. ReWater includes a special innovation section to find the right solutions for processing and resource utilisation."*

2.4: Other waste sources, including industry

The annual waste statistics (Miljøstyrelsen, 2024) categorises wastes from 20 types of industry. Of these, organic wastes would alone stem from food processing industries and industries producing beverages and tobacco. Of all industries, the food processing industry is by far the one, from which the largest amounts of wastes are generated, namely 411 out of 1,147 thousand tonnes in 2022 from all 20 industry types, whereas the beverages and tobacco industry only produce 10 thousand tonnes of wastes annually. Our understanding is that waste amounts from the beverage industry is far the largest share, but it is already being used for animal feed, therefore not available for processing into fertiliser.

When looking into the waste types, the Danish waste statistics presents two types of nutrient-containing wastes, namely

- Food waste; and
- Organic waste – other

In the further, it is these waste types that are analysed, and it is emphasized that they, alike the case is for wastewaters, originates from both households and industries.

2.4.1: Food waste

Food wastes collected in 2022 are according to Miljøstyrelsen (2024) amounting to 401 thousand tonnes. It is collected from households as well as from canteens, restaurants, etc., but also from food processing industry. In Denmark, food wastes should be separated and collected from households from 2021, but due to delays, this is first expected to be fully operational in 2024. We have assumed (own estimate) that the food wastes collected will amount 475 thousand tonnes in 2024, and the development thereafter follow the forecasted number of inhabitants.

Estimating the content of N and P in food wastes is even more uncertain than that of sludge. We have decided to use a publication by Słopiecka et al. (2022), saying that the nitrogen content ranges from 0.05% to 6.15%, while the phosphorus content ranges from 0 to 3.66%. Pragmatically, using averages of these figures means that 1 tonnes of food wastes would contain 31 kg N and 18.3 kg P.

Considering the huge and growing amounts of food wastes collected in Denmark, it could be expected that information about its chemical content would be known and nutrient recycling from food wastes be a concrete politically determined goal. However, a written enquiry to the waste company Kredsløb in Aarhus municipality did not enlighten the issue. Kredsløb informed that

- There is no goal for recycling of nutrients from food wastes or any other wastes.
- Kredsløb has no information about or expectations to the amounts of N and P in collected food wastes.

Kredsløb informs that the collected food wastes are disposed of to privately owned biogas plants. In Denmark, private owned biogas plants are used for anaerobic digestion of livestock manures as the primary influent, and the food wastes is thus being co-digested with manure and its NP nutrients contained in the resulting digestate being used as fertiliser for crop production.

2.4.2: Organic waste - other

The waste statistics of Miljøstyrelsen (2024) says the annual production was 683 thousand tonnes in 2022.

The waste statistics does not specify very clear what these organic wastes are. It is here assumed these other organic wastes covers:

- Slaughterhouse wastes, including stomach waste from slaughter animals.
- Dead animals - carcasses of animals that have died other than by being slaughtered.

Slaughterhouse wastes and dead animals are processed by DAKA⁷, formerly a farmer cooperative, and now a division of the large multinational SARIA business group. The handled waste types are surrounded by a certain degree of secrecy, partly considered company secrets and partly because the fear is that the figures could be used for criticizing livestock farming for not doing enough to reduce livestock mortality.

For assessing the collected amounts of N and P, we use figures given by the LEX4BIO project in the case of slaughterhouse wastes⁸, and assumes the rest amount is dead animals. None of this is informed with any regional distribution, but according to our information it is all related to Region Midtjylland since it is collected and processed at two main DAKA factories there, one in Hedensted and another one in Assentoft. The exact year the LEX4BIO data is valid for is not informed but is anticipated to be relatively new, i.e. less than five years old. We assume that 2034 data will follow the assumed trend for the development in number of livestock in Denmark, explained in section 2.2.2 above.

LEX4BIO informs that there is produced 601,917 thousand tonnes of slaughterhouse wastes in Denmark annually. This fits well with the Danish waste statistics, saying there is produced 683,000 tonnes of other organic wastes in 2022, and a simple estimate⁹ of the amount being dead animals, amounting to roughly to 80,000 tonnes annually.

⁷ <https://www.secanim.dk/>

⁸ https://px.luke.fi/PxWeb/pxweb/en/maatalous/maatalous_biomassa_Biowaste%20from%20food%20industry/Slaughter%20Waste%20National.px/table/tableViewLayout2/

⁹ The estimate is based on information about dead farming livestock, for instance given in https://www.landbrugsinfo.dk/-/media/landbrugsinfo/public/7/0/c/landsgennemsnit_production_grise_2022_notat_2315.pdf

For dead animals, the following is assumed with respect to the content of nutrients:

- The N content is 25 kg per ton, based on information provided by National Academics Press¹⁰, and
- The P content is 8.1 kg per ton, based on information provided by MicroFeeder¹¹ - the information is related to a cow, and it is assumed that other types of animals have similar content of P in their bodies.

The recycling share of nutrients from dead animals and slaughterhouse wastes is unknown. Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen (2023) informs that there for the planning year 2021/22 is sold 13,484 tons organic fertilisers in Denmark, containing 830 tons N and 208 tons P. DAKA informs at their webpage that there is produced 17 kg Øgro bio-based fertiliser from a 80 kg slaughter pig, and since Øgro fertilisers typically contain 10 kg N (6 to 14 kg N) and 3 kg P (0 to 3 kg P) per 100 kg, the corresponding amount of nutrients that would maximally be recycled from dead animals is 12.5 kg N and 3.75 kg P per ton. Since DAKA's Øgro series of bio-based fertilisers according to our information is dominating the market, we assume from these figures the present recycling of nutrients from other organic wastes. However, the traded amount organic fertilisers are sharply increasing, and has grown 100% over 2 years, since the planning period 2019/20, and we believe it will grow to the double before 2034.

¹⁰ <https://nap.nationalacademies.org/read/10586/chapter/15>

¹¹ <https://www.microfeeder.com/Aboutmineralfeeds>

3: Analysis of nutrient demand, supply and balance

This section presents the concrete assessments, including specific comments to the applied methodology and scenarios as described in section 2.

3.1: Nutrient demand

Table 3 shows the assessed demand for N and P in fertilisers in 2034. The demand for the entire country is divided on the five NUTS2 regions in Denmark. The nutrient demand is aggregated from demands for agriculture and horticulture, greenhouse production and private gardens.

Table 3: Estimated demand for N and P in fertilisers in 2034 for Danish NUTS2 regions and the whole country. Total figures are rounded off. Figures are given in ton.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|------------------------------|--------------------|--------------|-----------------|--------------|-------------------|---------------|--------------------|---------------|--------------------|--------------|----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Agriculture and horticulture | 10,859 | 1,445 | 60,465 | 8,274 | 95,758 | 13,377 | 94,451 | 13,337 | 58,781 | 8,217 | 320,315 | 44,650 |
| Greenhouse production | 20 | 4 | 190 | 40 | 25 | 5 | 125 | 26 | 17 | 3 | 376 | 79 |
| Private gardens | 333 | 48 | 366 | 52 | 545 | 78 | 543 | 78 | 276 | 39 | 2,064 | 295 |
| Total demand | 11,212 | 1,497 | 61,022 | 8,367 | 96,329 | 13,460 | 95,119 | 13,440 | 59,074 | 8,260 | 323,000 | 45,000 |

For agriculture and horticulture, the area foreseen to be grown/planted with different crop groups in 2034 is shown in Annex 1, as well as the estimated nutrient demand per ha for the individual crop type groups. The nutrient demand for the individual crop type group is not calculated after any formula, but roughly estimated, attempting to give weight to the most dominant crop within the crop type group, and the nutrient demand for the most productive soil types, given that less productive soils will be converted to nature and forests following the "Green agreement".

The estimated nutrient demand for greenhouses is based on statistics about the regional distribution of greenhouses in Denmark in 2020¹². However, since the regional distribution alone cover greenhouses with an area above 1,000 m², which is only about 36% of all greenhouses, an extrapolation of the regional distribution with a factor 2.74 was done – see Annex 2. In addition, it is assumed that greenhouses in Denmark are closed systems, not regulated according to the normal harmony rules for agriculture and horticulture. The N and P demands are higher in such intensive and

¹² <https://www.statistikbanken.dk/20474>

controlled all-year greenhouse production, where the main crops comprise tomatoes, cucumber and pot plants. N and P demands are estimated on basis of guiding levels for individual crops given by Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen (2024). We have no indications for changes in the greenhouse production area or the distribution on crops for the next 10 years. We believe that field production of some type of crops, including strawberries, would be covered and become greenhouse production in the coming years due to more and more extreme weather conditions, but such a change would not affect the nutrient demand since fertilisation would still be regulated under the so-called harmony rules.



Strawberries damaged by hailstorm.

In Table 3, the total figures are rounded off since it is not reliable to make a 10-years forecast with a higher precision than 1,000-ton N and P nutrient.

The estimated nutrient demands for garden fertilisation of single-family houses and farmhouses in Table 3 is based on the regional distribution shown in Annex 3.

3.2: Nutrients in organic wastes from farming

The estimated amounts of manure and its content of N and P nutrients for different animal types is shown in Annex 4:

- For cattle, the figures are generally relating to standard values for dairy cattle, but for cows, these figures are reduced with approximately 10% to reflect that a part of the cattle also in

2034 is expected to be beef cattle, thus considering that beef cows have a considerably lower manure production than dairy cows.

- For chicken, the assessments assume a relation between the number of egg-laying hens and slaughter chickens, including broilers, ducks, turkeys and gees.
- For horses and sheep, neither statistics nor standard values for manure are very precise, and they are for instance not specified on animal types.

Following the specifications given in Annex 4 and 5, Table 4 shows the amount of manure nutrients that is expected to be produced by livestock in 2034, as well as their expected effective utilisation for the “Do nothing” scenario.

Table 4: Estimated N and P nutrients in livestock manure in 2034 in Danish NUTS2 regions, and for the whole country for the “Do nothing” scenario. Total figures are rounded off. All figures are expressed as ton.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|--|--------------------|-----|-----------------|-------|-------------------|--------|--------------------|--------|--------------------|--------|----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | 4,389 | 999 | 3,723 | 3,359 | 66,794 | 14,223 | 62,073 | 13,876 | 46,752 | 10,325 | 193,732 | 42,781 |
| Reduction for accepted losses, 22.5% N / 15% P | 988 | 150 | 3,088 | 504 | 15,029 | 2,133 | 13,967 | 2,081 | 10,519 | 1,549 | 43,590 | 6,417 |
| Estimated net nutrient supply with manures | 3,402 | 849 | 10,636 | 2,855 | 51,765 | 12,089 | 48,107 | 11,794 | 36,233 | 8,776 | 150,000 | 36,000 |

Similarly, Table 5 shows the amount of manure nutrients that is expected to be produced by livestock in 2034, as well as their expected effective utilisation for the “Optimised” scenario, given the assumed NUE improvements mentioned in section 2.2, i.e. reduced losses from both livestock housing, manure storage and field spreading.

Table 5: Estimated N and P nutrients in livestock manure in 2034 in Danish NUTS2 regions, and for the whole country for the "Optimised" scenario. Total figures are rounded off. All figures are expressed as ton.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|--|--------------------|-----|-----------------|-------|-------------------|--------|--------------------|--------|--------------------|--------|----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | 4,389 | 999 | 13,723 | 3,359 | 66,794 | 14,223 | 62,073 | 13,876 | 46,752 | 10,325 | 193,732 | 42,781 |
| Corrected for 5% lower N volatilisation from housing and storage | 4,609 | 999 | 14,410 | 3,359 | 70,134 | 14,223 | 65,177 | 13,876 | 49,090 | 10,325 | 203,419 | 42,781 |
| Reduction for expected loss, 11.25% N, 0% P | 518 | - | 1,621 | - | 7,890 | - | 7,332 | - | 5,523 | - | 22,885 | - |
| Estimated nutrient supply with manures | 4,090 | 999 | 12,789 | 3,359 | 62,244 | 14,223 | 57,845 | 13,876 | 43,567 | 10,325 | 181,000 | 43,000 |

The livestock manure types behind the nutrients in Table 4 and 5 comprise solid and liquid manure types, slurry and deep bedding.

Most of the manure is collected, but a part of it is dropped during grazing, therefore not available for controlled fertilisation, although contributing to the crop nutrition. About 10% of the Danish cattle production is of beef breeds, who graze in the summertime, half of the year. Also, about 10% of the cattle production is organic (Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen, 2022), meaning the cattle must be grazed in the summertime. It is uncertain how organic livestock production will develop until 2034. Organic dairy cows are normally grazed, but only in the daytime. Horses and sheep are normally kept outdoors half of the year. Concludingly, there may probably be 5 - 10% of the manure nutrients that are dropped during grazing.

3.3: Nutrients in urban wastewater

Table 6 gives the expected amounts of N and P nutrients in wastewaters in 2034, given the forecasted number of inhabitants in Danish NUTS2 regions, as appears from Annex 7 and the nutrients per pe as clarified in section 2.3.

Table 6 also shows the amount of nutrients that is returned to farming as sludge for crop fertilisation, based on information in the Danish waste statistics (Miljøstyrelsen, 2024) and the used nutrient content, informed in section 2.3. Our impressions of the ReWaste case, representing future's wastewater treatment, gives no basis for assuming a higher share of nutrients in wastewaters will return to farming in 2034. We consider it for likely that ReWaste's plans to cease the return of sludge to farming may be weighed up by yet unclear processing that will enable other and more safe streams

of nutrient recycling. The share of nutrient recycling from wastewaters in 2034 is thus assumed to be the same as for 2022 according to the Danish waste statistics.

Table 6: Expected amount of nutrients in urban wastewater in 2034.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---------------------|--------------------|-------|-----------------|-----|-------------------|-------|--------------------|-------|--------------------|-----|-------------|-------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | 8,519 | 1,936 | 3,791 | 862 | 5,501 | 1,250 | 6,072 | 1,380 | 2,631 | 598 | 26,514 | 6,026 |
| Returned to farming | 200 | 135 | 89 | 60 | 129 | 87 | 142 | 96 | 62 | 42 | 622 | 420 |

Table 6 assumes that the recycling share of nutrients in wastewaters is the same in all regions.

3.4: Nutrients in other waste sources, including industry

In the following is analysed nutrients in food wastes, dead animals and slaughterhouse wastes that potentially could be used for production of bio-based fertilisers.

3.4.1: Nutrients in food wastes

Table 7 presents the amount of nutrients in 2034 in food wastes returned to farming, based on the methodology and considerations described in section 2.4.1. It is assumed that the regional distribution is equal to the population distribution. Assuming that food wastes in accordance with information from the waste collection company Kredsløb in Aarhus Municipality all is disposed of to private biogas plants and co-digested with manure, it is anticipated that the nutrients in this waste type is 100% effectively recycled to farming.

Table 7: Expected amount of nutrients in food wastes that will be returned to farming in 2034 in the form of digestate or processed products thereof, both in case of the "Do nothing" and the "Optimised" scenarios.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---------------|--------------------|-------|-----------------|-------|-------------------|-------|--------------------|-------|--------------------|-----|-------------|-------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | 4,773 | 2,818 | 3,083 | 1,820 | 3,083 | 1,820 | 3,403 | 2,009 | 1,474 | 870 | 14,857 | 8,770 |

3.4.2: Nutrients in other organic wastes

Table 8 presents the estimated amounts of nutrients in slaughterhouse wastes. The estimates are based on the considerations and methodologies that are explained in section 2.4.2. This means that the nutrients in slaughterhouse wastes follow the information provided by LEX4BIO, forecasted to 2034, assuming the methodology for forecasting the number of livestock as explained in section 2.2.2, with the number of expected livestock in 2034 shown in Annex 5.

It is assumed that the current recycling of nutrients in slaughterhouse wastes is 40%, and that this due to policy changes in support of the market for bio-based fertilisers will increase to 80% in 2034.

To our information, slaughterhouse waste and dead animals are brought to DAKA factories for processing in either Hedensted or Assentoft, in both cases in Region Midtjylland.

Table 8: Expected amount of nutrients in slaughterhouse wastes and the expected share of it that will be returned to farming in 2034, both in case of the "Do nothing" and the "Optimised" scenarios.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---------------------|--------------------|---|-----------------|---|-------------------|---|--------------------|-------|--------------------|---|-------------|-------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | - | - | - | - | - | - | 13,923 | 3,123 | - | - | 13,923 | 3,123 |
| Returned to farming | - | - | - | - | - | - | 11,139 | 2,498 | | | 11,139 | 2,498 |

Similarly, Table 9 shows the estimated total amounts on nutrients in collected dead animals in 2034, and the assumed recycling to farming.

The current amounts of dead animals are based on figures in the Danish waste statistics for other organic wastes, subtracted the LEX4BIO informed amounts of slaughterhouse wastes. Amounts for 2034 are based on forecasted livestock number in the same way as for slaughterhouse wastes.

It is assumed that the current recycling of nutrients in slaughterhouse wastes is 40%, and that this due to policy changes in support of the market for bio-based fertilisers will increase to 80% in 2034.

Table 9: Expected amount of nutrients in dead animals and the expected share of it that will be returned to farming in 2034, both in case of the "Do nothing" and the "Optimised" scenarios.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---------------------|--------------------|---|-----------------|---|-------------------|---|--------------------|-----|--------------------|---|-------------|-----|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Gross amounts | - | - | - | - | - | - | 1,806 | 585 | - | - | 1,806 | 585 |
| Returned to farming | - | - | - | - | - | - | 1,084 | 351 | | | 1,084 | 351 |

3.5: Resulting nutrient balances

The following Table 10 shows the estimated nutrient demand, supply and balance in the current situation, based on available latest updated statistics, supplemented with estimates and assumptions, as clarified in the previous sections. An overall nutrient balance is calculated by adding the consumed amounts of traded fertilisers according to Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen (2023). The resulting total balance per ha agricultural area, including inorganic fertilisers and including accepted losses of manure nutrients, 38 kg N and 7 kg P, is different from

information provided by HELCOM¹³, which, however, is not updated since 2015, and the same is the matter for EEA and Eurostat information. However, it is important to understand that nutrient balances shall be interpreted on basis of the methodology used for calculation of them, and that different institutions use different methodologies. The aim of the calculated balances is to illustrate how large a share of the nutrient demand that could be covered by recycled nutrients and, how the consumption of inorganic fertilisers could change in 2034 in case the “Do nothing” or the “Optimised” scenario is realised.

The situation in the five Danish regions is in short as follows:

- Region Hovedstaden, which includes Copenhagen, has a low crop production and a low livestock production, but a relatively large supply of nutrients from WW sludge, food wastes and other organic wastes. Overall surplus of P.
- Region Sjælland has a high crop production, but a low livestock production, overall leading to a large undersupply of both N and P.
- The three regions Syddanmark, Midtjylland and Nordjylland have all a high livestock production and a high crop production, but a relatively low number of inhabitants. Overall, they all have a demand for more N, but a surplus of P.

Table 11 summarises the nutrient demands and nutrient supply for the “Do nothing” scenario. The large influence of the “Green agreement” is clearly seen when comparing figures for nutrient demands and supply with manure with the same figures in Table 10. The need for inorganic N fertilisers is in this scenario reduced with 50,098 tons N, equal to a reduction of 21%. The P balance is, compared to the current situation, increased with 5,153 tons P, which would allow a P export of 3,945 tonnes P.

The nutrient demand and supply for the “Optimised” scenario is shown in Table 12. The scenario assumes a higher recycling of nutrients via less volatilisation from livestock houses, manure storages and field spreading of manure, some increased recycling of nutrients in other organic wastes, etc. Implementing this scenario would mean that the consumption of inorganic N fertilisers could be reduced with 110,881 tonnes of N, equal to 47%, and that there would be surplus of more than 10,000 tons P, which could be exported.

¹³ <https://indicators.helcom.fi/indicator/agricultural-nutrient-balance/>

Potentials for higher recycling of nutrients in organic wastes from farming, industry and households - The current situation and scenarios for future development in Danish NUTS2 regions

Table 10: Nutrient balances for Denmark and Danish NUTS2 regions in the current situation, based on available latest updated statistics in 2024, supplemented with estimates and assumptions. All figures in tonnes unless otherwise informed.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|--|--------------------|--------------|-----------------|---------------|-------------------|---------------|--------------------|---------------|--------------------|--------------|-----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Nutrient demand for field crops, adjusted for quota utilisation | 12,776 | 1,700 | 71,136 | 9,735 | 112,657 | 15,738 | 111,119 | 15,690 | 69,154 | 9,667 | 376,842 | 52,530 |
| Nutrient demand for greenhouses | 20 | 4 | 190 | 40 | 25 | 5 | 125 | 26 | 17 | 3 | 376 | 79 |
| Nutrient demand for private gardens | 333 | 48 | 366 | 52 | 545 | 78 | 543 | 78 | 276 | 39 | 2,064 | 295 |
| Estimated nutrient demand for crop production | 13,129 | 1,752 | 71,692 | 9,827 | 113,227 | 15,821 | 111,787 | 15,793 | 69,447 | 9,710 | 379,283 | 52,904 |
| Nutrients in livestock manures, ex storage | 4,824 | 1,095 | 15,344 | 3,751 | 74,538 | 15,845 | 69,364 | 15,492 | 52,085 | 11,489 | 216,155 | 47,672 |
| Reduction for accepted field loss, 22,5% / 15% | 1,085 | 164 | 3,452 | 563 | 16,771 | 2,377 | 15,607 | 2,324 | 11,719 | 1,723 | 48,635 | 7,151 |
| Estimated nutrient supply with manures | 3,738 | 931 | 11,891 | 3,189 | 57,767 | 13,469 | 53,757 | 13,168 | 40,366 | 9,765 | 167,520 | 40,522 |
| Recycled nutrients in food wastes | 4,731 | 2,793 | 2,105 | 1,243 | 3,055 | 1,804 | 3,372 | 1,991 | 1,461 | 863 | 14,725 | 8,693 |
| Recycled nutrients in other organic wastes - slaughterhouse wastes | | | | | | | 6,250 | 1,402 | | | 6,250 | 1,402 |
| Recycled nutrients in other organic wastes - dead animals | | | | | | | 608 | 197 | | | 608 | 197 |
| Estimated nutrient supply from other wastes, including industry | 4,731 | 2,793 | 2,105 | 1,243 | 3,055 | 1,804 | 10,230 | 3,589 | 1,461 | 863 | 21,583 | 10,291 |
| Nutrients i wastewater | 8,443 | 1,919 | 3,757 | 854 | 5,453 | 1,239 | 6,018 | 1,368 | 2,608 | 593 | 26,279 | 5,972 |
| Returned to crop production from WWTP's | 1,249 | 284 | 556 | 126 | 806 | 183 | 890 | 202 | 386 | 88 | 3,887 | 883 |
| Balance of the above | -3,411 | 2,255 | -57,140 | -5,269 | -51,599 | -365 | -46,909 | 1,166 | -27,234 | 1,005 | -186,293 | -1,208 |
| Consumption of inorganic fertilisers | | | | | | | | | | | 238,016 | 11,689 |
| Total balance, including consumption of inorganic fertilisers | | | | | | | | | | | 51,723 | 10,481 |
| Total balance per ha agricultural area, including inorganic fertilisers and including accepted losses of manure nutrients, kg | | | | | | | | | | | 38 | 7 |

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Table 11: Nutrient balances for Denmark and Danish NUTS2 regions for the 2034 "Do Nothing" scenario. All figures are tonnes unless otherwise informed.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---|--------------------|--------------|-----------------|--------------|-------------------|---------------|--------------------|---------------|--------------------|--------------|----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Nutrient demand for field crops, adjusted for quota utilisation | 10,859 | 1,445 | 60,465 | 8,274 | 95,758 | 13,377 | 94,451 | 13,337 | 58,781 | 8,217 | 320,315 | 44,650 |
| Nutrient demand for greenhouses | 20 | 4 | 190 | 40 | 25 | 5 | 125 | 26 | 17 | 3 | 376 | 79 |
| Nutrient demand for private gardens | 333 | 48 | 366 | 52 | 545 | 78 | 543 | 78 | 276 | 39 | 2,064 | 295 |
| Estimated nutrient demand for crop production | 11,212 | 1,497 | 61,022 | 8,367 | 96,329 | 13,460 | 95,119 | 13,440 | 59,074 | 8,260 | 322,755 | 45,024 |
| Nutrients in livestock manures, ex storage | 4,389 | 999 | 13,723 | 3,359 | 66,794 | 14,223 | 62,073 | 13,876 | 46,752 | 10,325 | 193,732 | 42,781 |
| Reduction for accepted field loss, 22,5% / 15% | 988 | 150 | 3,088 | 504 | 15,029 | 2,133 | 13,967 | 2,081 | 10,519 | 1,549 | 43,590 | 6,417 |
| Estimated nutrient supply with manures | 3,402 | 849 | 10,636 | 2,855 | 51,765 | 12,089 | 48,107 | 11,794 | 36,233 | 8,776 | 150,143 | 36,364 |
| Recycled nutrients in food wastes | 4,773 | 2,818 | 3,083 | 1,820 | 3,083 | 1,820 | 3,403 | 2,009 | 1,474 | 870 | 14,857 | 8,770 |
| Recycled nutrients in other organic wastes - slaughterhouse wastes | | | | | | | 11,139 | 2,498 | | | 11,139 | 2,498 |
| Recycled nutrients in other organic wastes - dead animals | | | | | | | 1,084 | 351 | | | 1,084 | 351 |
| Estimated nutrient supply from other wastes, including industry | 4,773 | 2,818 | 3,083 | 1,820 | 3,083 | 1,820 | 15,625 | 4,858 | 1,474 | 870 | 27,079 | 11,620 |
| Nutrients i wastewater | 8,519 | 1,936 | 3,791 | 862 | 5,501 | 1,250 | 6,072 | 1,380 | 2,631 | 598 | 26,514 | 6,026 |
| Returned to crop production from WWTP's | 200 | 135 | 89 | 60 | 129 | 87 | 142 | 96 | 62 | 42 | 622 | 420 |
| Balance of the above | -2,838 | 2,305 | -47,214 | -3,632 | -41,352 | 536 | -31,245 | 3,308 | -21,305 | 1,428 | -143,953 | 3,945 |
| Consumption of inorganic fertilisers | | | | | | | | | | | 187,918 | 4,964 |
| Total balance, including consumption of inorganic fertilisers | | | | | | | | | | | 43,965 | 8,909 |
| Total balance per ha agricultural area, including inorganic fertilisers and including accepted losses of manure nutrients, kg | | | | | | | | | | | 36 | 6 |

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Table 12: Nutrient balances for Denmark and Danish NUTS2 regions for the 2034 "Optimised" scenario. All figures are tonnes unless otherwise informed.

| | Region Hovedstaden | | Region Sjælland | | Region Syddanmark | | Region Midtjylland | | Region Nordjylland | | All Denmark | |
|---|--------------------|--------------|-----------------|--------------|-------------------|---------------|--------------------|---------------|--------------------|---------------|----------------|---------------|
| | N | P | N | P | N | P | N | P | N | P | N | P |
| Nutrient demand for field crops, adjusted for quota utilisation | 10,859 | 1,445 | 60.465 | 8.274 | 95.758 | 13.377 | 94.451 | 13.337 | 58.781 | 8.217 | 320.315 | 44.650 |
| Nutrient demand for greenhouses | 20 | 4 | 190 | 40 | 25 | 5 | 125 | 26 | 17 | 3 | 376 | 79 |
| Nutrient demand for private gardens | 333 | 48 | 366 | 52 | 545 | 78 | 543 | 78 | 276 | 39 | 2.064 | 295 |
| Estimated nutrient demand for crop production | 11,212 | 1,497 | 61.022 | 8.367 | 96.329 | 13.460 | 95.119 | 13.440 | 59.074 | 8.260 | 322.755 | 45.024 |
| Nutrients in livestock manures, ex storage | 4,389 | 999 | 13.723 | 3.359 | 66.794 | 14.223 | 62.073 | 13.876 | 46.752 | 10.325 | 193.732 | 42.781 |
| Corrected for 5% lower N volatilisation from housing and storage | 4,609 | 999 | 14.410 | 3.359 | 70.134 | 14.223 | 65.177 | 13.876 | 49.090 | 10.325 | 203.419 | 42.781 |
| Reduction for accepted field loss, 22,5% / 15% | 518 | - | 1,621 | - | 7,890 | - | 7,332 | - | 5,523 | - | 22,885 | - |
| Estimated nutrient supply with manures | 4,090 | 999 | 12,789 | 3,359 | 62,244 | 14,223 | 57,845 | 13,876 | 43,567 | 10,325 | 180,534 | 42,781 |
| Recycled nutrients in food wastes | 4,773 | 2,818 | 3,083 | 1,820 | 3,083 | 1,820 | 3,403 | 2,009 | 1,474 | 870 | 15,815 | 9,336 |
| Recycled nutrients in other organic wastes - slaughterhouse wastes | - | - | - | - | - | - | 11,139 | 2,498 | - | - | 11,139 | 2,498 |
| Recycled nutrients in other organic wastes - dead animals | - | - | - | - | - | - | 1,084 | 351 | - | - | 1,084 | 351 |
| Estimated nutrient supply from other wastes, including industry | 4,773 | 2,818 | 3,083 | 1,820 | 3,083 | 1,820 | 15,625 | 4,858 | 1,474 | 870 | 28,038 | 12,185 |
| Nutrients i wastewater | 8,519 | 1,936 | 3,791 | 862 | 5,501 | 1,250 | 6,072 | 1,380 | 2,631 | 598 | 26,514 | 6,026 |
| Returned to crop production from WWTP's | 200 | 135 | 89 | 60 | 129 | 87 | 142 | 96 | 62 | 42 | 622 | 420 |
| Balance of the above | -6,923 | 2,455 | -48,144 | -4,948 | -33,956 | 849 | -37,132 | 532 | -15,445 | 2,107 | -113,562 | 10,362 |
| Consumption of inorganic fertilisers | | | | | | | | | | | 127,135 | -10,362 |
| Total balance, including consumption of inorganic fertilisers | | | | | | | | | | | 13,573 | 0 |
| Total balance per ha agricultural area, including inorganic fertilisers and including accepted losses of manure nutrients, kg | | | | | | | | | | | 27 | 0 |

4: Conclusion and discussion

4.1: Conclusion

The following figures 1-2 visualises the overall NP nutrient balances for Danish NUTS2 regions and total for Denmark in the current situation and the expected situation in 2034, whether the “Do nothing” or the “Optimised” situation will prevail.

The figures illustrate quite well that the self-sufficiency with NP nutrients for crop fertilisation would be substantially improved as a result of the implementation of the “Green agreement”, which is the most important assumption for the “Do nothing scenario”, and also the further impact on self-sufficiency and nutrient balances in case nutrient losses in farm could be halved, which is the additional main assumption for the “Optimised” scenario.

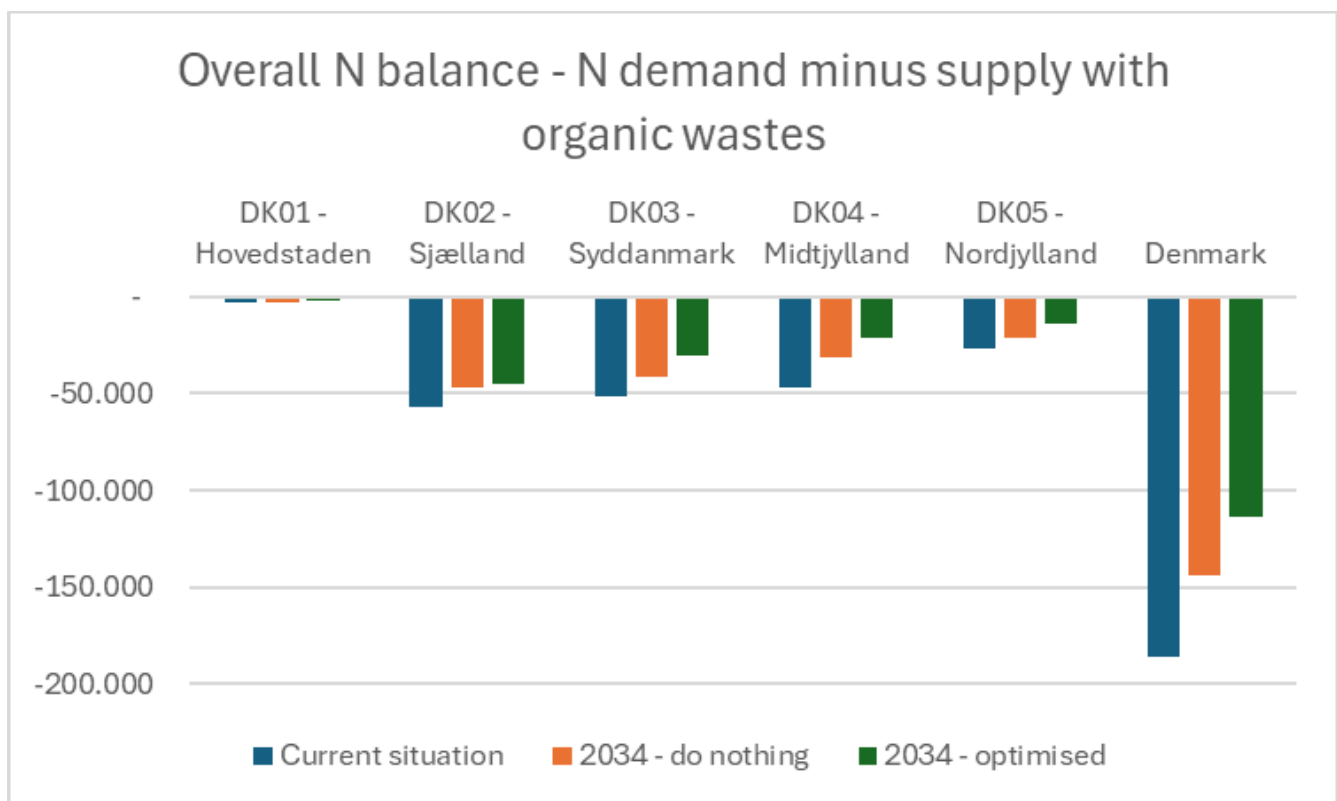


Figure 1: Overall N balance for Danish NUTS2 regions and Denmark in total in the current situation and the expected situation in 2034 for the “Do nothing” and the “Optimised” scenarios.

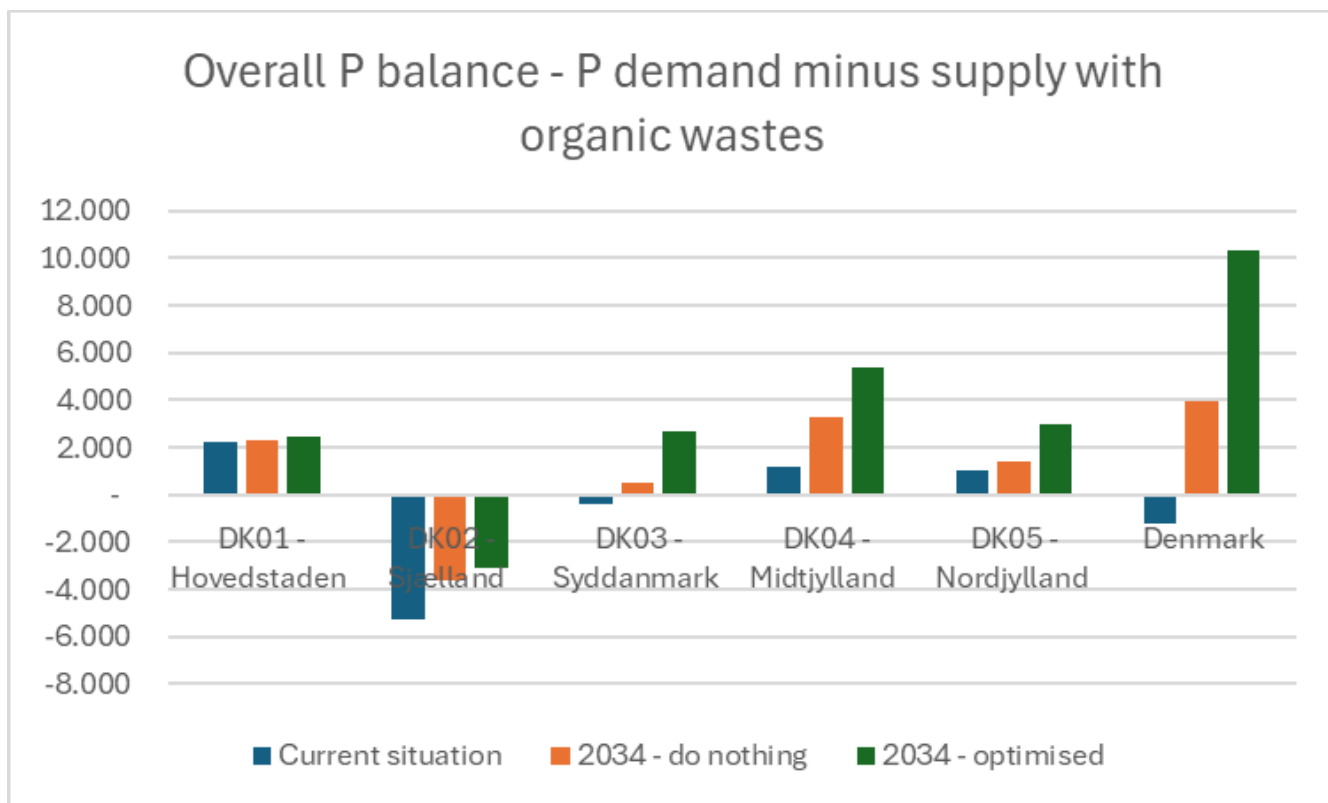


Figure 2: Overall P balance for Danish NUTS2 regions and Denmark in total in the current situation and the expected situation in 2034 for the "Do nothing" and the "Optimised" scenarios.

Some important details and aspects of the analysed results are highlighted in the following.

4.1.1: Current nutrient recycling and self-sufficient

The analysis of nutrient balances in Denmark and Danish NUTS2 regions shows that it would be possible already in the current situation, to reduce the import of P fertilisers with 90%, since Denmark overall only has a small P deficit compared to the demand for crop production. Overall, the self-sufficiency with N and P from recycled organic wastes is 51 and 98%, respectively.

Of 192,990 recycled tonnes N, 87% relates to livestock manures. The regulated N field effect of about 77.5% means that it is accepted that 22.5% or 48,635 tonnes N may be lost to the environment.

Overall, the analysis exposes the huge role of farming in future solutions for increased recycling and self-sufficiency with plant nutrients and, vice versa, for improving the quality of air and water. The figures also reveal a very low recycling of nutrients from other organic waste types, especially those collected from households.

4.1.2: Expected nutrient recycling and self-sufficiency in 2034 for the "Do nothing" scenario

The "Do nothing" scenario for 2034 is generally speaking assuming business as usual with respect to recycling of nutrients in organic wastes. It is for instance assuming that the present N field effect of averagely about 77.5% is maintained and that the current measures to limit ammonia volatilisation

from livestock stables and manure stores remains unchanged. Another important assumption is that the number of livestock will continue to decline, and that the current large export of piglets will remain.

However, it is assumed that the nutrient recycling from dead animals and slaughterhouse wastes is doubled, compared to the current situation.

The main reason for the "Do nothing" scenario to result in substantial lower nutrient demands is the assumption that the "Green agreement" will be implemented and reduce the cultivated and fertilised area with about 15%.

The self-sufficiency with N and P, meaning the share of the nutrient demand that is covered with recycled nutrients is increased from 51 and 98% for N and P respectively, to 55 and 109%. The lower nutrient demand following the "Green agreement" is largely weighed up by a substantial smaller livestock manure production in the case of N, while the self-sufficiency with P is influenced by increased recycling from food wastes and WW sludge, also considering the expected development in population. All NUTS2 regions would have a N deficit, while it is relevant to reallocate recycled P among regions, since NUTS2 region DK02, Sjælland, has a deficit of P, while the other four regions have surplus. The following Figure 3 and 4 shows the N and P demand, supply and balances for Danish NUTS2 regions.

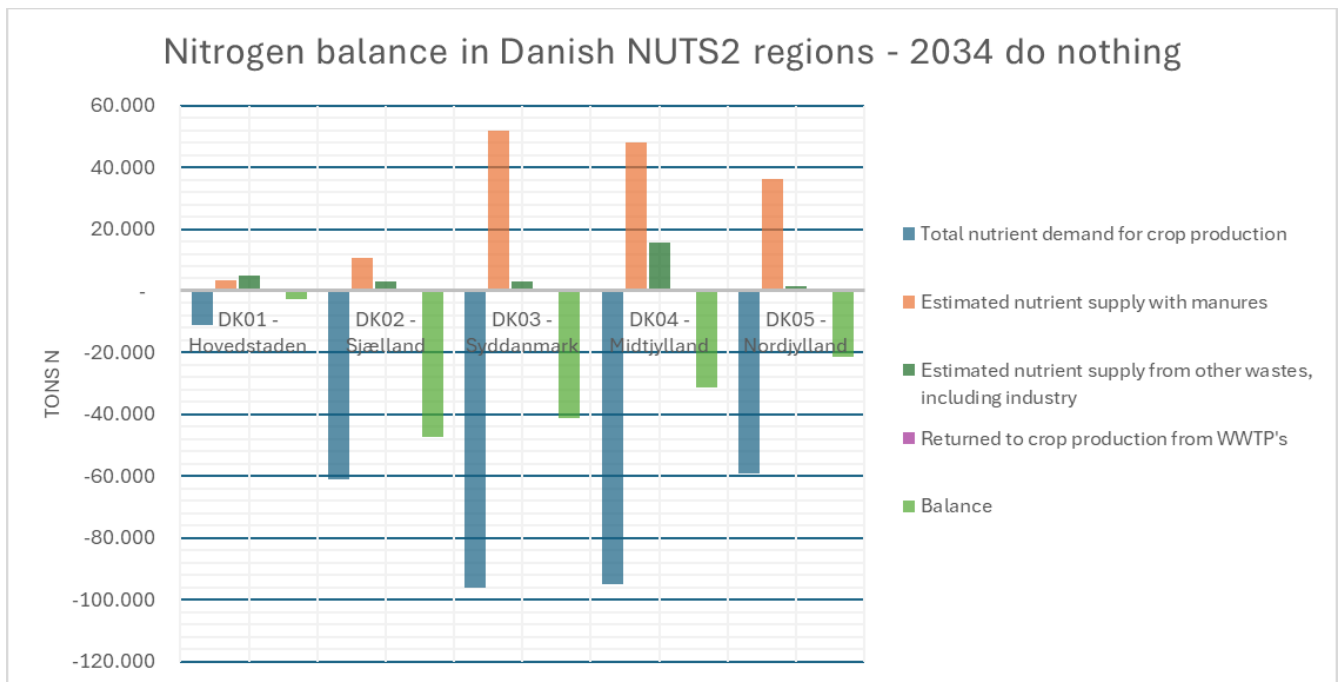


Figure 3: N demand, supply and balances for Danish NUTS2 regions for the "Do nothing" scenario.

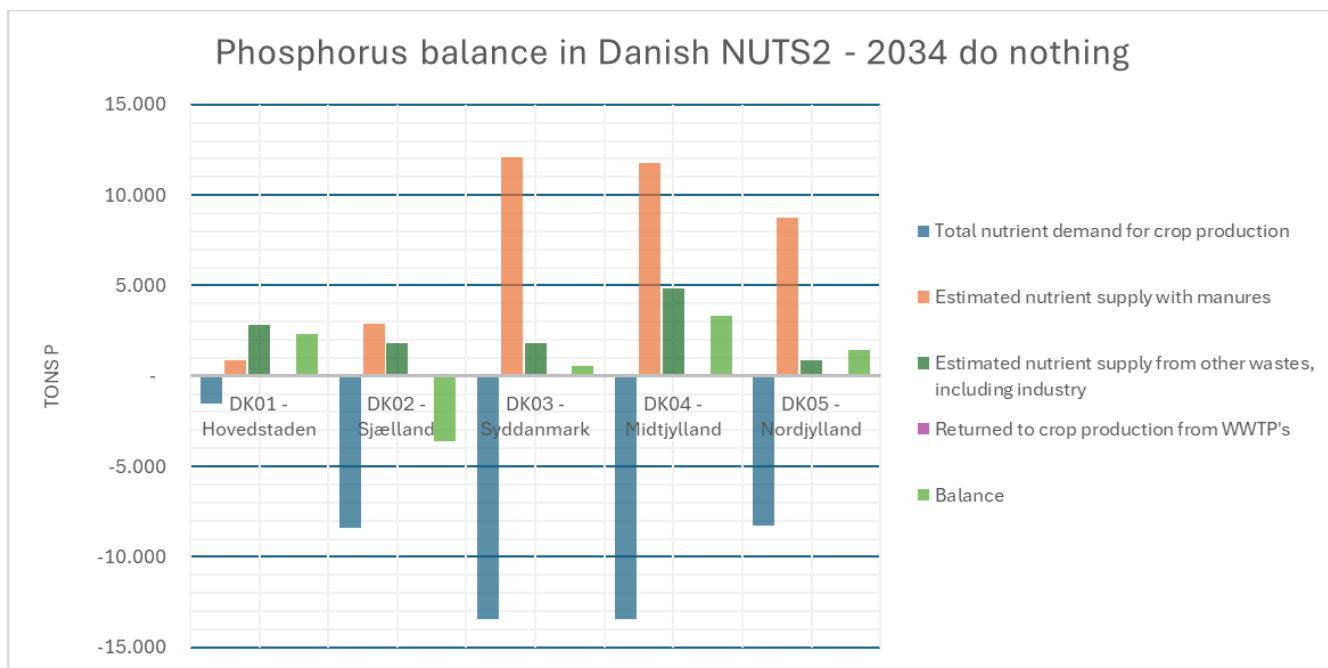


Figure 4: P demand, supply and balances for Danish NUTS2 regions for the "Do nothing" scenario.

4.1.3: Expected nutrient recycling and self-sufficiency in 2034 for the "Optimised" scenario

The "Optimised" scenario builds on the assumptions for the "Do nothing" scenario, but are in addition assuming that further measures are introduced to reduce losses of nutrients in farming, in specific that it will be possible to reduce ammonia volatilisation overall with 50%, in specific to reduce ammonia losses from livestock stables and manure storages from 10% to 5% of the N ex animal, and similarly that the N field effect is increased from averagely 77.5% to 88.75%. Also, the scenario assumes introduction of required maximal farm nutrient balances, at least in the case of P, which is assumed to be averagely 0 kg P per ha.

The halving of the losses of N and the elimination of P losses in farming would have direct effect on the overall N and P balances, that would be reduced to 13,573 tonnes N and 0 tonnes P.

Implementation of this scenario would mean a self-sufficiency with N and P of 65 and 123%, respectively, a considerable increase from the current self-sufficiency of 51 and 98%. The increased self-sufficiency means that the consumption of N fertiliser could be reduced with 47% and there would be possibility for a net export of P out of the country of 10,362 tonnes of P. The changes would overall mean that Denmark by far would exceed the Farm-to-Fork goals shown in Table 1 for both N and P. However, it is reminded that the Farm-to-Fork goals are expected to be realised by 2030, whereas the "Optimised" scenario is assumed to be realised by end of 2034.

The following Figure 5 and 6 shows the N and P demand, supply and balances for Danish NUTS2 regions.

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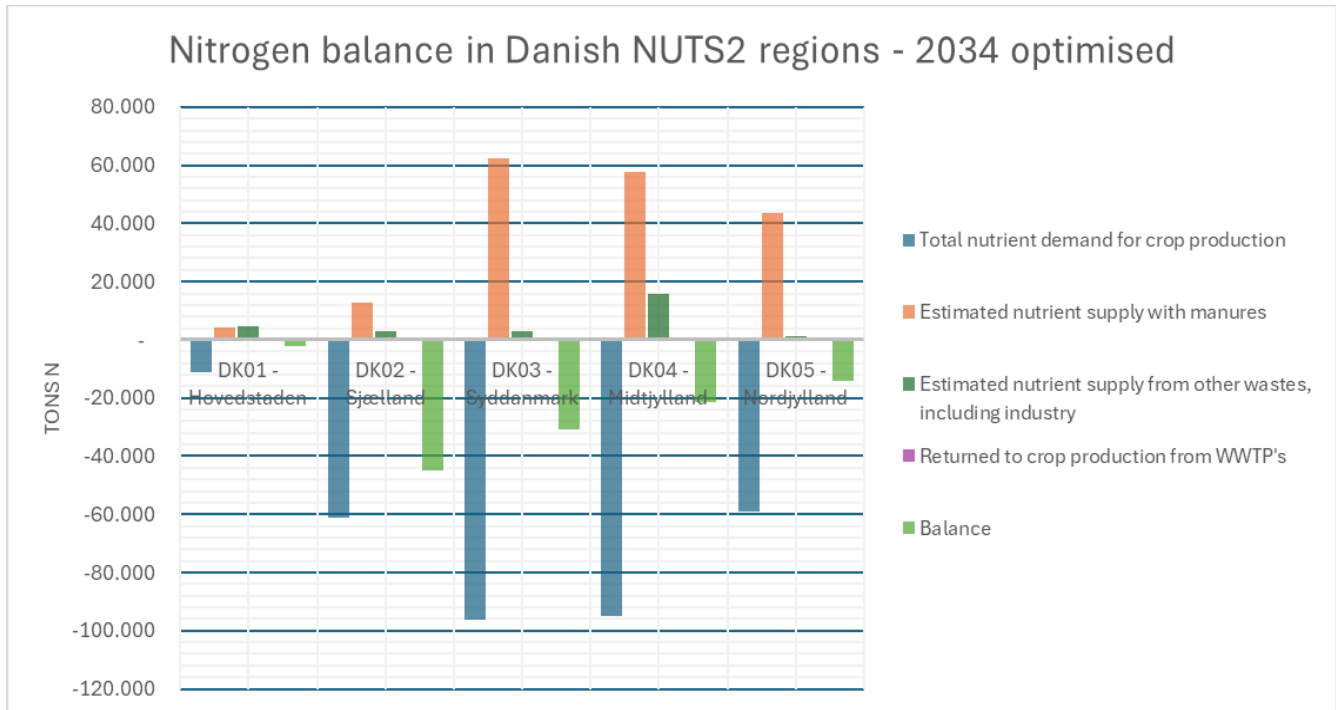


Figure 5: N demand, supply and balances for Danish NUTS2 regions for the "Optimised" scenario.

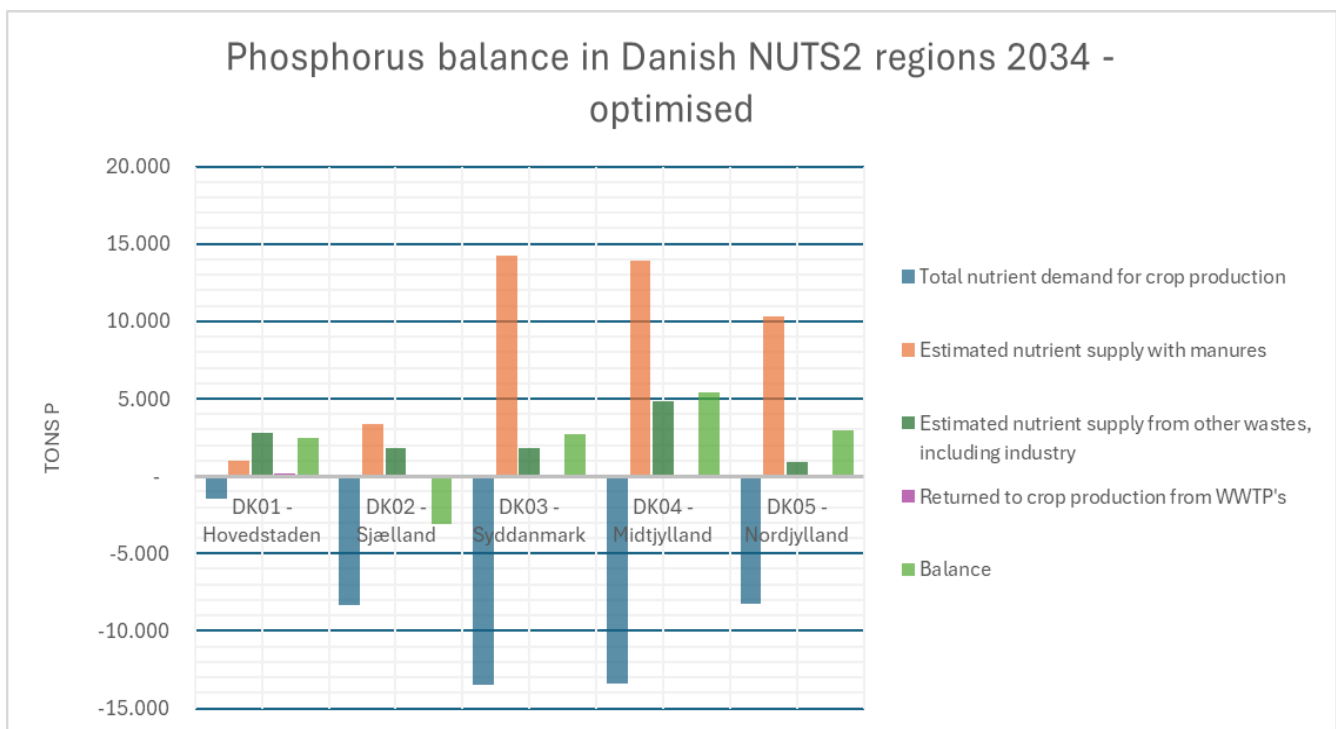


Figure 6: P demand, supply and balances for Danish NUTS2 regions for the "Optimised" scenario.

4.2: Discussion

The nutrient recycling and self-sufficiency for the scenarios "Do nothing" and "Optimised" are estimated by a wide use of assumptions, as clarified under section 2 about methodologies, and the conclusions must therefore be taken with some reservation.

In the following is listed some considerations for the main assumptions.

- The demand for plant nutrients for field crops is assessed with some uncertainties, since for instance the cropping pattern in 2034 is based on estimated forecasts, and similar for the nutrient demands and productivity for the individual crops.

The analyses assumes that the "Green agreement" will be implemented as agreed in June 2024. However, the "Green agreement" is largely based on voluntary measures, and the current policy discussions in November 2024 reveals that farmers do not find the economic compensations they would be offered for sufficiently attractive. This could give uncertainty about the implementation of the "Green agreement". It is in this respect reminded that the "Do nothing" scenario in many ways is an assessment of the effect of the "Green agreement" with respect to nutrient balances and self-sufficiency, since other pre-assumptions used for that scenario are of less importance.

- It can be discussed whether farmers actually do fertilise up to the legal maximum, as assumed in this report. According to Figure 7, which is based on analysis of farmers reporting of their fertiliser plans to the authorities, this is not the case. An opposing information is given by a report from Rigsrevisionen (2024), who informs that inspections at 3.7% of the Danish farms revealed a consumption of N in fertilisers that in the years 2019 to 2022 have been 243-370 ton above the legal limit. Extrapolating the average of these years, 307 tons of N per year, to 100% of Danish crop production means, that Danish farmers use averagely 8,300 tons N more than the legal

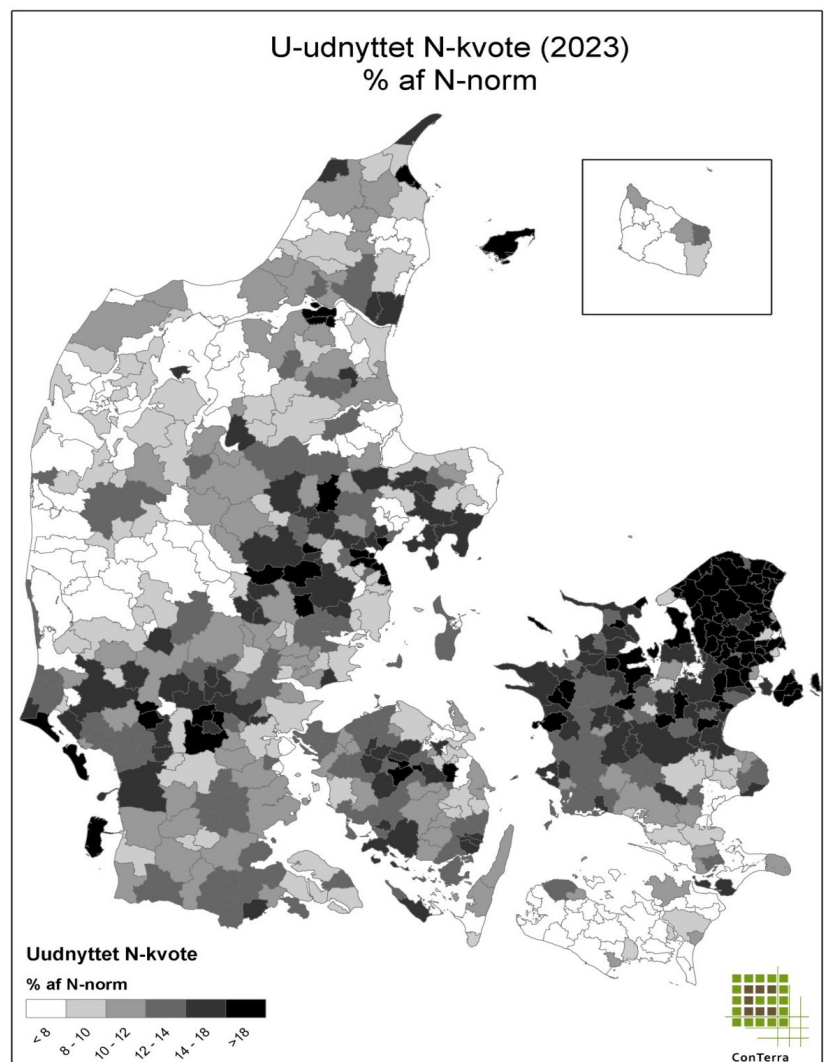


Figure 7: Un-utilised share of the maximally regulated N-fertilisation (In Danish: Uudnyttet N-kvote) in Denmark in 2023 (Source: ConTerra).

limit, which is about 2.5% of the N demand according to Table 10. Execution is often deviating much from plans, and the analysis of this report gives most weight to the result of the farm inspections and has by combining the abovementioned information pragmatically assumed that farms averagely fertiliser according to the legal maximum according to Ministeriet for Fødevarer, Landbrug og Fiskeri, Landbrugsstyrelsen (2023a).

- The report assesses the nutrient demand for fertilising private gardens. The assessment in Table 3 is only equal to 0.7% of the total nutrient demand for crop production. For comparison, we know from statistics on pesticide sales (Miljøstyrelsen, 2022) that 1.9% of active ingredients in sold plant protection products are bought for use in private gardens. There may also be other use of plant nutrients that is not included in the assessment, such as fertilisers used at golf courses and fertilisers used in connection to the planting of new forests.
- The export of alive pigs, mainly piglets and in some cases fatteners ready for slaughter, is assumed to be 45% of the weaned piglets in 2034. This is the level of expert that is expected in 2024. The export has a large importance for the number of pigs, the manure production from the pigs and it also affects the amounts of dead animals and slaughterhouse wastes. The following figure 6 shows the development in the export since 2007.

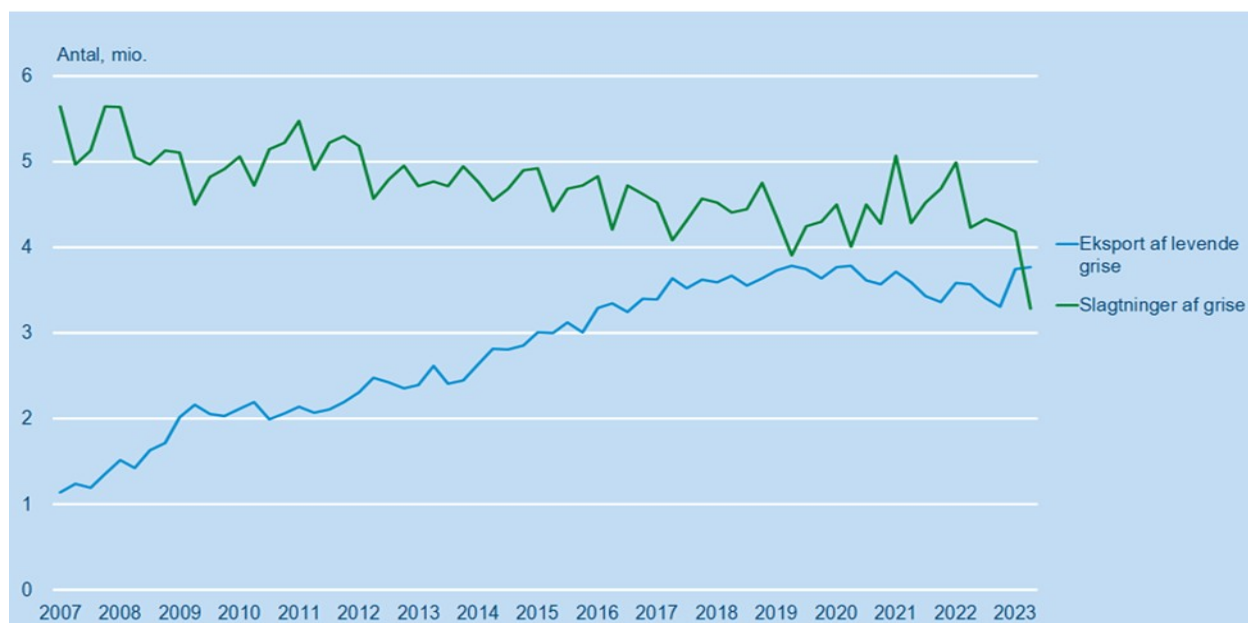


Figure 6: Development in the quarterly export of alive pigs (green curve) and the number slaughtered in Denmark. Source: (Statistics Denmark¹⁴.)

You could read the curves in the figure in the way that there is a more or less clear trend toward all piglets or fatteners being exported. Another way to read the figure is to focus on

¹⁴ <https://www.dst.dk/da/Statistik/nyheder-analyser-publ/bagtal/2023/2023-11-03-stigende-eksport-af-grise-paavirker-den-danske-bestand>

the last 5 years, where there has actually not been much development. Analyses in this report assumes that the export in 2034 will remain in the same level as in 2024, according to agricultural media to be 45% of the weaned piglets.

- The “Optimised” scenario has as the most important pre-condition assumed that nitrogen losses from stables and manure storages, as well as the losses during field spreading of manure is halved.

There are huge potentials finding ways for achieving a higher N field effect – with other words to avoid losses of nitrogen from the cropped fields. It could in this connection be questioned whether the accepted field losses of N, averagely about 22.5%, is still justifiable considering recent advancements in precision nutrient management and manure processing and field spreading technology. Section 2.2.3 is mentioning examples of technologies that would be instrumental in reaching that goal, and tables 10-12 is clearly showing the large impact this would have on the self-sufficiency with nutrients, and vice-versa the possibility to reduce the environmental load of farming if that goal would be possible to reach.

Similarly, the analysis shows that it might still be relevant to give better incentives for a better distribution of available P in livestock manures and other organic wastes. There is no justification for an average P farm balance higher than 0 kg per ha. In this respect, Denmark does not comply with the HELCOM (2007) recommendation of a max of 25 kg P per ha, but even better would be to introduce required P farm balances of 0 kg P per ha, which can happen with a minimum of impact on the farming economy (Arate et al., 2022). Separation of slurry would have a large role in reaching the goal of a balanced P use, and both anaerobic digestion and slurry acidification cause major improvements in the plant availability of P in manures.

- The amount of nutrients that is recycled from slaughterhouse wastes and dead animals was assessed with even very large uncertainty and had to be based on relatively loose assumptions. Similarly, it was recognised, that information about nutrient turnover related with food wastes largely does not exist. It appears to be inappropriate in relation to a variety of policy goals, that companies working with nutrient rich organic wastes, either public owned companies or companies that like DAKA is given total dominance and responsibility for handling specific waste types, are not demanded to have nutrient accounts, set goals for their nutrient recycling and requested to openly publish figures about their activities.

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Annex 1: Expected area with specific crop type groups and their nutrient demands in 2034

| Crop type group | 1,000 ha | | | | | | Nutrient demand | |
|---------------------------------------|--------------------|-----------------|-------------------|--------------------|--------------------|-------------|-----------------|---------|
| | Region Hovedstaden | Region Sjælland | Region Syddanmark | Region Midtjylland | Region Nordjylland | All Denmark | Kg N/ha | Kg P/ha |
| 1.1 Winter cereals | 45 | 251 | 348 | 376 | 215 | 1.235 | 190 | 22 |
| 1.2 Spring cereals | 29 | 139 | 174 | 186 | 119 | 647 | 150 | 22 |
| 2. Pulses | 16 | 112 | 174 | 190 | 96 | 588 | 0 | 27 |
| 3. Root crops | 2 | 7 | 16 | 14 | 7 | 45 | 160 | 41 |
| 4. Industrial crops | 1 | 32 | 19 | 30 | 14 | 96 | 195 | 30 |
| 5. Seeds | 10 | 55 | 53 | 56 | 39 | 213 | 180 | 10 |
| 6. Grass and whole crop | 4 | 42 | 28 | 24 | 11 | 109 | 175 | 25 |
| 7. Horticultural crops | 11 | 22 | 190 | 145 | 113 | 481 | 175 | 30 |
| 8. Permanent pastures | 1 | 3 | 6 | 5 | 1 | 17 | 0 | 0 |
| 9. Christmas trees and greenery | 17 | 30 | 68 | 68 | 52 | 235 | 100 | 10 |
| 10. Fallow | 0 | 2 | 7 | 7 | 3 | 21 | 0 | 0 |
| 11. Miscellaneous | 7 | 27 | 45 | 50 | 37 | 166 | 0 | 0 |
| Agriculture and horticulture in total | 83 | 400 | 665 | 663 | 420 | 2.232 | | |

Annex 2: Nutrient demand in 2034 for greenhouse production

| | 1,000 m ² | | | | | | Nutrient demand | |
|--|----------------------|-----------------|-------------------|--------------------|--------------------|-------------|-----------------|---------|
| | Region Hovedstaden | Region Sjælland | Region Syddanmark | Region Midtjylland | Region Nordjylland | All Denmark | Kg N/ha | Kg P/ha |
| Greenhouse area in total ¹⁵ | 359 | 1,539 | 338 | 1,131 | 184 | 3,551 | | |
| Including tomato | 6 | 263 | 30 | 9 | 6 | 313 | 2,350 | 535 |
| Including cucumber | 15 | 379 | 15 | 2 | 2 | 413 | 2,100 | 430 |
| Including pot plants | 137 | 344 | 123 | 1,179 | 132 | 1,915 | 950 | 195 |

¹⁵ According to <https://www.statistikbanken.dk/20474>. For the regional distribution, adjusted by extrapolation with a factor 2.74.

Annex 3: Single family houses and farmhouses in 2024¹⁶ and their assessed nutrient demands for private garden fertilisation

| Region | Number of family houses and farmhouses | Assumed nutrient demand for private garden fertilisation, ton | |
|--------------------|--|---|-----|
| | | N | P |
| In total | 1,179,589 | 2,320 | 295 |
| Region Hovedstaden | 190,399 | 333 | 48 |
| Region Sjælland | 209,253 | 366 | 52 |
| Region Syddanmark | 311,610 | 545 | 78 |
| Region Midtjylland | 310,544 | 543 | 78 |
| Region Nordjylland | 157,783 | 276 | 39 |

¹⁶ <https://www.statistikbanken.dk/20064>

Annex 4: Manure nutrient production

Amounts and nutrient content are based on Børsting and Hellwing (2023), in some cases adjusted on basis of considerations indicated in section 3.2. All figures express ex storage values.

| | Counts | Produced per year | Ton manure/ place/ year | Ton manure/ produced/ year | Ton manure, total | Kg N/ place/ year | Kg N/ produced/ year | Kg N, total | Kg P/ place/ year | Kg P/ produced/ year | Kg P, total |
|--------------------------------------|--------|-------------------|-------------------------|----------------------------|-------------------|-------------------|----------------------|-------------|-------------------|----------------------|-------------|
| PIGS | | | | | | | | | | | |
| Sows, including piglets up to 6,7 kg | 110 | 100 | | 5,9 | 587 | | 20,59 | 2.059 | | 4,70 | 470 |
| Piglets, 6,7 - 31 kg | 20 | 3.254 | | 0,128 | 417 | | 0,366 | 1.191 | | 0,10 | 321 |
| Slaughter pigs 31 - 115 kg | 348 | 1.406 | | 0,533 | 749 | | 2,39 | 3.360 | | 0,45 | 627 |
| Gilts | 45 | 50 | | 3,0 | 150 | | 10 | 500 | | 2,20 | 110 |
| Boars | 10 | 10 | | 4,5 | 45 | | 15 | 150 | | 3,50 | 35 |
| Total | 533 | 4.820 | | | 1.948 | | | 7.260 | | | 1.563 |
| Value per average pig count | 1 | 9,1 | | | 3,7 | | | 13,6 | | | 2,9 |
| CATTLE | | | | | | | | | | | |
| Cows | 100 | 100 | | 28.0 | 2,800 | | 140 | 14,000 | | 22.0 | 2,200 |
| Calves 0-6 months | 55 | 110 | 1.89 | | 104 | 26.7 | | 1,469 | 3.28 | | 180 |
| Heifers 6 months to calving | 96 | 52.25 | 6.44 | | 617 | 45.2 | | 4,330 | 6.62 | | 634 |
| Young animals from 6 months to | 30.48 | 52.25 | | 2.21 | 115 | | 18.1 | 946 | | 2.69 | 141 |

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| | Counts | Produced per year | Ton manure/ place/ year | Ton manure/ produced/ year | Ton manure, total | Kg N/ place/ year | Kg N/ produced/ year | Kg N, total | Kg P/ place/ year | Kg P/ produced/ year | Kg P, total |
|--------------------------------|--------|-------------------|-------------------------|----------------------------|-------------------|-------------------|----------------------|-------------|-------------------|----------------------|-------------|
| slaughter | | | | | | | | | | | |
| Total | 281 | 314.5 | | | 3,636 | | | 20,744 | | | 3,155 |
| Value per average cattle count | 1 | 1.12 | | | 12.9 | | | 73.8 | | | 11.2 |

CHICKENS

| | | | | | | | | | | | |
|-------------------------------------|------|-------|--|------|-------|--|------|-------|--|------|-------|
| Hens (100) | 100 | 100 | | 1.82 | 182 | | 41.7 | 4,170 | | 18.2 | 1,820 |
| Slaughter chickens (1000) | 7.50 | 67.5 | | 1.37 | 92.48 | | 33.8 | 2,282 | | 8.2 | 554 |
| Total | 108 | 167.5 | | | 274 | | | 6,452 | | | 2,374 |
| Value per average 100 chicken count | 1 | 1.56 | | | 2.6 | | | 60.0 | | | 22.1 |

SHEEP

| | | | | | | | | | | | |
|-------------------------------|-----|------|--|-----|------|--|------|-------|--|-----|------|
| Sheep | 100 | 100 | | 1.1 | 113 | | 14.6 | 1,460 | | 3.1 | 313 |
| Total | 100 | 100 | | | 113 | | | 1,460 | | | 313 |
| Value per average sheep count | 1 | 1.00 | | | 1.13 | | | 14.60 | | | 3.13 |

HORSES

Potentials for higher recycling of nutrients in organic wastes from farming, industry and households - The current situation and scenarios for future development in Danish NUTS2 regions

| | Counts | Produced per year | Ton manure/ place/ year | Ton manure/ produced/ year | Ton manure, total | Kg N/ place/ year | Kg N/ produced/ year | Kg N, total | Kg P/ place/ year | Kg P/ produced/ year | Kg P, total |
|-------------------------------|--------|-------------------|-------------------------|----------------------------|-------------------|-------------------|----------------------|-------------|-------------------|----------------------|-------------|
| Horse | 100 | 100 | | 4.5 | 452 | | 34.8 | 3,480 | | 7.1 | 705 |
| Total | 100 | 100 | | | 452 | | | 3,480 | | | 705 |
| Value per average horse count | 1 | 1.00 | | | 4.52 | | | 34.80 | | | 7.05 |

Annex 5: Number of farm animals in 2023 and expected in 2034, distributed on NUTS2 regions

| 2023 - Source: Danmarks Statistik, https://www.statistikbanken.dk/20472 | Pigs | Cattle | Chickens | Sheep | Horses |
|--|-------------------|------------------|-------------------|----------------|---------------|
| Region Hovedstaden | 230,420 | 27,381 | 1,073,843 | 8,837 | 7,154 |
| Region Sjælland | 1,131,132 | 64,312 | 730,157 | 22,758 | 7,600 |
| Region Syddanmark | 3,119,370 | 568,684 | 7,972,359 | 57,329 | 9,534 |
| Region Midtjylland | 3,759,988 | 442,546 | 5,671,694 | 37,390 | 10,525 |
| Region Nordjylland | 2,582,472 | 339,580 | 7,185,863 | 26,258 | 10,569 |
| TOTAL | 10,823,382 | 1,442,503 | 22,633,916 | 152,572 | 45,382 |

| Estimate 2034: 1,000 heads, adjusted with minus 10% for cattle and pigs, and for pigs furthermore assumed that 45% of piglets are exported. All figures are rounded. | Pigs | Cattle | Chickens | Sheep | Horses |
|--|--------------|--------------|---------------|------------|-----------|
| Region Hovedstaden | 103 | 24 | 1,074 | 9 | 7 |
| Region Sjælland | 503 | 57 | 730 | 23 | 8 |
| Region Syddanmark | 1,388 | 506 | 7,972 | 57 | 10 |
| Region Midtjylland | 1,673 | 394 | 5,672 | 37 | 11 |
| Region Nordjylland | 1,149 | 302 | 7,186 | 26 | 11 |
| TOTAL | 4,816 | 1,283 | 22,634 | 152 | 47 |

Annex 6: Characteristics of manure types

The estimation of the livestock manure production uses the same 10 categories of livestock manure as defined by Foged et al. (2010), extended with horse and sheep manure. The figures for chemical values are generally based on selected values provided by Børsting and Hellwing (2023) in some cases also on indications given by the ATLAS of biomasses in AgroTechnologyATLAS¹⁷

| | Solid pig manure | Liquid pig manure | Pig slurry | Pig deep litter | Solid cattle manure | Liquid cattle manure | Cattle slurry | Cattle deep litter | Poultry slurry | Poultry deep litter | Horse manure | Sheep manure |
|---|------------------|-------------------|------------|-----------------|---------------------|----------------------|---------------|--------------------|----------------|---------------------|--------------|--------------|
| Dry matter (DM) content, % | 23 | 2.08 | 5.54 | 33 | 20.23 | 3.23 | 9.29 | 30 | 12 | 44 | 26 | 34.6 |
| Total nitrogen (N), kg per ton | 11.09 | 3.08 | 4.31 | 2.41 | 6.39 | 4.61 | 5.3 | 9.74 | 6.18 | 19.86 | 7.1 | 12.9 |
| NH ₄ -N, kg per ton | 3.88 | 3.08 | 3.21 | 2.41 | 1.57 | 4.61 | 3.14 | 1.95 | 4.02 | 6.43 | 1.77 | 3.23 |
| Total phosphorus (calculated as pure P), kg per ton | 5.08 | 0.21 | 0.96 | 3.28 | 1.74 | 0.16 | 0.88 | 1.55 | 1.59 | 4.55 | 1.56 | 2.77 |
| Potassium (calculated as pure K), kg per ton | 8.88 | 1.88 | 2.35 | 12.75 | 3.53 | 22.53 | 5.2 | 11.6 | 2.6 | 11.43 | 11.7 | 27 |

¹⁷ <https://www.agrotechnologyatlas.eu>

Annex 7: Danish citizens in 2024 and forecasted for 2034, distributed on NUTS2 regions

| | Region Hovedstaden | Region Sjælland | Region Syddanmark | Region Midtjylland | Region Nordjylland | Denmark |
|--------------------------------|--------------------|-----------------|-------------------|--------------------|--------------------|-----------|
| Number, 2024 ¹⁸ | 1,918,855 | 853,885 | 1,239,234 | 1,367,809 | 592,637 | 5,972,420 |
| Forecasted, 2034 ¹⁹ | 1,936,035 | 861,530 | 1,250,329 | 1,380,055 | 597,943 | 6,025,893 |
| Percent distribution | 32.1 | 14.3 | 20.7 | 22.9 | 9.9 | 100 |

¹⁸ <https://www.statbank.dk/statbank5a/SelectVarVal/Define.asp?Maintable=FOLK1A&PLanguage=0>

¹⁹ The forecast for 2034 is made as an interpolation of the forecast for 2070, made by Statistics Denmark - <https://www.statistikbanken.dk/20021>



This report presents an “Potentials for higher recycling of nutrients in organic wastes from farming, industry and households”, applying future “Do nothing” and “Optimised” scenarios for 2034, which among other assumes the recent “Green agreement” is implemented. Among important conclusions are that Denmark and Danish NUTS2 regions will be much less dependent on consumption of inorganic fertilisers in 2034 if the “Green agreement” is implemented, and that there is a huge potential in halving losses of N and P from stables, manure storages and field spreading of manure. Already today, 98% of P fertilisers could be based on recycled P if this was evenly distributed in Denmark, and there is potential for a relatively large export of surplus P out of the country in 2034. While nutrients in municipal and industrial wastes can play an increasing role, and especially the newly implemented collection of household food wastes contribute more to the nutrient supply, it is farming that primarily has the potential to improve nutrient recycling.

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